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CLIMATE AND WEATHER

By H. N. DICKSON, M.A., D.Sc., Oxon., F.R.S.E.

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CLIMATE AND WEATHER

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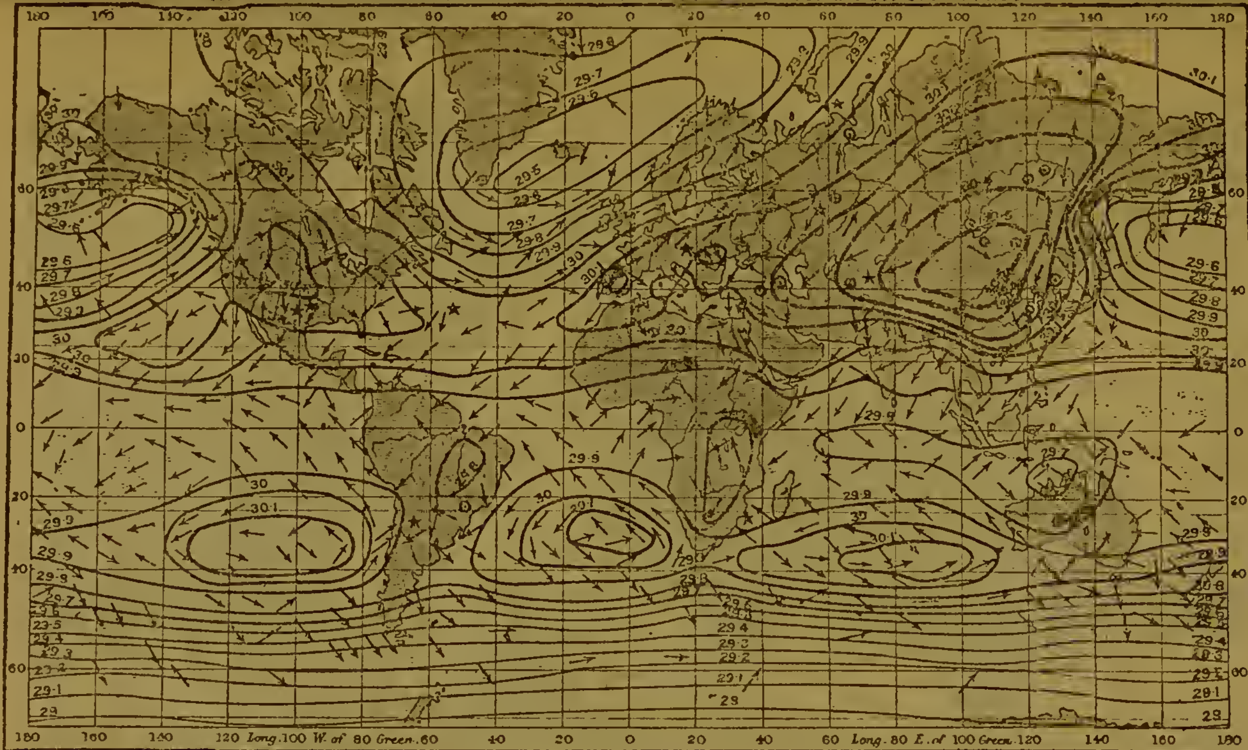

Variable Winds ★ Calms _O

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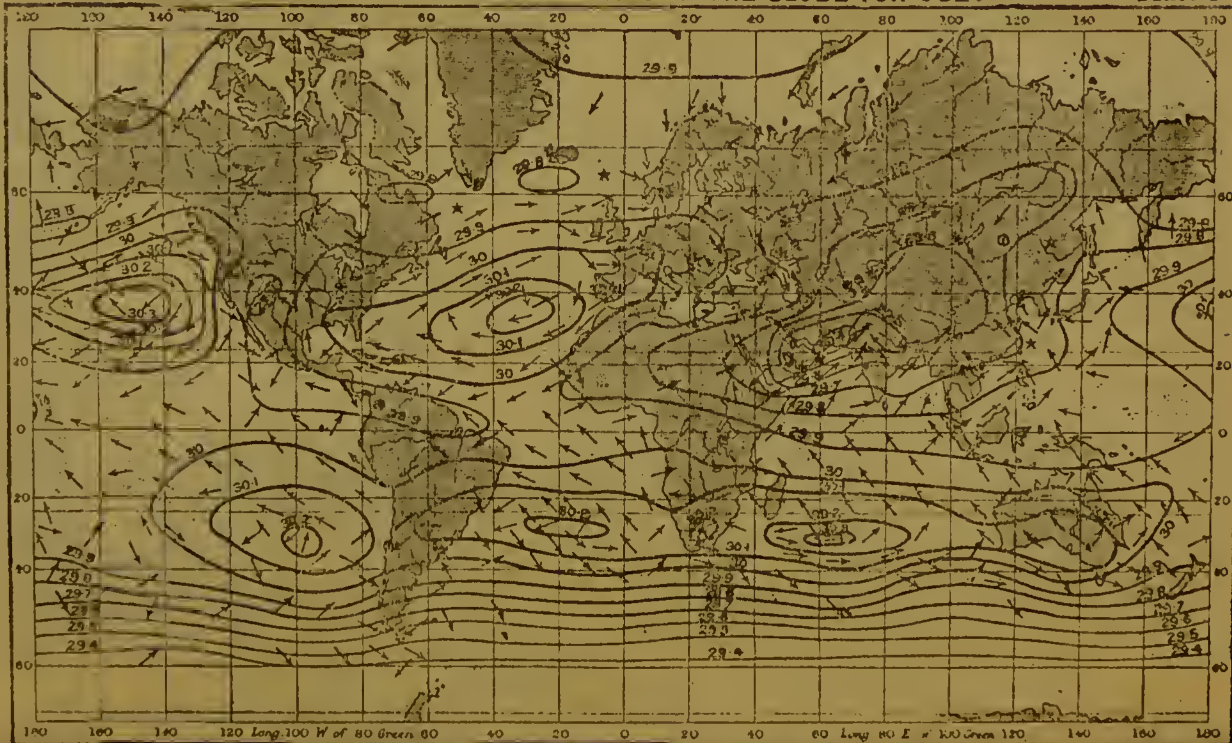
MEAN ISOBARS AND PREVAILING WINDS OF THE GLOBE FOR JULY

Plate 2



Variable Winds ★ Calms ⊙

CLIMATE AND WEATHER

CHAPTER I

PRELIMINARY CONSIDERATIONS

The surface of the earth is enclosed by the Atmosphere. This atmosphere is complex in its composition, but within certain narrow limits that composition remains constant, in the lower levels at all events, over the whole globe: chemical analysis yields nearly identical results from whatever region the atmospheric sample may be derived. On the other hand, partly because of the different exposures of different places to the sun, and partly because of the different properties of the land and sea surfaces, the physical condition of the atmosphere differs from one part to another, and varies from time to time in one part, to an extent which produces results of amazing importance. It is true that in their purely

physical aspect these differences and variations are small; a range of twice the difference between melting ice and boiling water, for example—a mere trifle compared to the difference between the accessible temperatures of boiling hydrogen and the electric arc—covers nearly all extremes of atmospheric temperature, yet at one end we have the frozen desert of the Siberian winter, and at the other the torrid wastes of the Sahara or Eastern Sind.

The somewhat unspellable and unpronounceable title Meteorology is given to the science which deals with these conditions and changes in the atmosphere. Meteorology is primarily a branch of applied physics: it will be our business to describe in outline some of these physical conditions in the atmosphere, and to state the results of some of the attempts which have been made to explain or account for them.

Before proceeding to examine the special case of the atmosphere it will, however, be desirable to describe shortly in this chapter some of the general conditions affecting the

earth's surface, and to compare their influences upon its different parts.

The gain and loss of heat at the surface are of paramount importance. Leaving out of account, as observation shows we may safely do, the small amounts of heat received by conduction from the earth's hot interior, we find that the only source of heat to be reckoned with is the sun. The sun does not itself give out heat, but it emits rays which are propagated as waves or ripples in the medium which pervades all space and is called the ether. These rays are of widely different wave-lengths, and some of them produce special effects when they impinge on specially prepared surfaces: thus some, falling upon the retina of the eye, produce impressions interpreted by the brain as light, and rays of different wave-lengths (within certain limits) give impressions of different coloured light, the aggregate of all the solar rays within the light limits giving the impression known as *white* light. Some rays, again, produce chemical effects upon certain compounds—

hence the whole group of phenomena which come under the domain of photography.

But the most important fact, for our purpose at least, is that when rays are stopped by meeting any surface which they cannot penetrate, their energy is converted into heat, and the temperature of the surface is raised. Many substances, such as those which go to form the land surface of the globe, stop these rays altogether—*i. e.* they are altogether opaque or "athermanous"; others partly stop them and partly transmit them, or stop rays of certain wave-lengths and transmit rays of others, as in the case of parts of the atmosphere (see Chapter III). In any case, the rays stopped or *absorbed* produce heating effect, those transmitted do not.

The amount of radiant energy given out in this way by the sun is enormous, the earth receiving but a minute fraction of the whole. It would serve no good purpose here to try to indicate actual amounts; but it is to be noted that for the purposes of meteorology the rate of emission may be regarded as constant throughout the periods of time considered.

But radiation is not confined to the sun. Any body possessing heat energy will give out rays, though if the temperature of the body is low the rays emitted will be "dark": *i.e.* they will not include rays capable of affecting the eye. The wave-lengths of the rays emitted, and the quantity of heat given out by radiation in a given time depends, in general, on the temperature of the emitting body. A smoothing-iron at its proper working temperature gives out rays which produce sensible heat effects on the cheek if tested in the usual way, although the iron is not visible in the dark. But if the iron is made hotter it not only gives out more heat, but it becomes "red" hot: hotter still it becomes "white" hot

The earth has long since passed the stages of white and red heat; but it continues to give out dark rays and so to lose heat by radiation into space, the rate of loss depending on the temperature at the radiating surface.

The temperature at any point of the earth's surface is the result of complex conditions. We have said that the rate of emission by the sun is practically constant, but the amount of

energy received by the earth at any point in a certain time depends on three things which vary: first, the distance of the sun from the earth; second, the length of the day; and third, the average altitude of the sun above the horizon during the day. [For explanation of the extent and causes of these variations, see any good elementary text-book of physical geography.] The point will receive more energy, and become hotter, the nearer the earth and sun are to each other, the longer the day, and the greater the sun's altitude, and conversely. But the hotter the point the greater the loss by radiation into space, or the more rapid the cooling, and again conversely. Hence the temperature at any time is a balance struck by the relative rates of gain from the sun and loss into space. We may compare it in fact to the balance maintained by the ordinary citizen in current account with his bank. At certain periods the rate of income is greater than that of expenditure, and the balance (temperature) rises; at others expenditure gains upon income, and the balance falls. It may even be legitimate to

press the analogy further, and say that the higher the balance rises the greater the expenditure becomes, so that it never rises above a certain point, and the lower the balance falls the more economy in expenditure is practised in order that the balance may not fall below a certain minimum. Income corresponds to insolation, expenditure to terrestrial radiation, and balance to temperature.

One result of the conditions of insolation [see again a text-book of physical geography] already mentioned must be emphasized as of great importance in meteorology. The variations in amount of radiant energy received are in general of two kinds, those taking place in (1) the length of the day (day being defined as time the sun is above the horizon), and (2) the average altitude of the sun above the horizon during the day. The range of all the variations is constant, and all the phases occur within a year (we have longest and shortest days, and highest and lowest average altitudes, within a year); and the values are, so far as meteorology is concerned, the same every year. Since the power of the sun is

regarded as constant, there is, therefore, no tendency to continuous heating or cooling, but merely to changes within certain defined limits. Further, taking the whole year, the length of the day and the average altitude during the day vary least in low latitudes where the average altitude is also greatest, and most in high latitudes where the average altitude is least. It follows that in low latitudes there is great difference of temperature between day and night and little from season to season of the year; and that as we get into higher latitudes the diurnal difference becomes less and the seasonal difference greater, until at the poles there is only "six months' day and six months' night."

Since the radiations of different wave-lengths from the sun do not change in their proportions, it follows that variations in heat effect, due wholly to changes in duration and manner of insolation at any place, will be associated with corresponding variations in light effects or chemical effects. This would be strictly true at the earth's surface if

there were no atmosphere. It is not quite true in fact, for one place may have a sunny climate with relatively low temperature, another a warm climate with comparatively little sunshine, as a result of atmospheric conditions. The point is of considerable importance in discussing the relation of sunshine and air-temperature to the growth of plants, as will be seen later (Chapter IX).

Like all other bodies on the surface of the earth which are not directly fixed thereon, and are therefore free to move, the conditions of rest or of movement in the atmosphere are controlled by the action of the universal force of gravity. It will be useful to draw attention here to some of the ways in which gravity acts. To get rid of complications due to the action of other forces, to be considered presently, let us suppose the earth to be at rest, *i. e.* not spinning upon its axis. At any point on the surface, gravity acts towards the centre of the earth in the direction of the straight line joining the point on the surface and the centre. We know of no method of

interfering with or modifying this action, and a body would consequently "fall," or follow the direction of this line, if the gravitational force were not met by a resistance, the "thrust" of the rigid surface of the earth, acting in an exactly opposite direction. Take the case of a smooth marble free to roll about on a smooth table: it will only remain at rest if the resistance offered by the table-top is perpendicular to the direction of gravity. If the table were removed the marble would follow the direction of gravity "downwards"; if the table inclined to the horizontal the resistance of its top would act partly in a sideways direction and the marble roll down the slope—a movement still partly downwards but also partly one of translation from one place to another. *If a body, free to move, is to remain at rest on a non-rotating earth, it must be acted upon by forces in a direction opposite to that of gravity and in no other.*

Now consider the case where the earth is rotating at its normal speed. A body "at rest" but free to move on its surface is really

spinning round in a circle at the same speed, and the circle is the parallel of latitude of the point on which it rests. The rate at which the body moves is evidently greater the lower the latitude, because the circles are larger, and the round journey has to be made in the same time as in higher latitudes, where the circles are smaller.

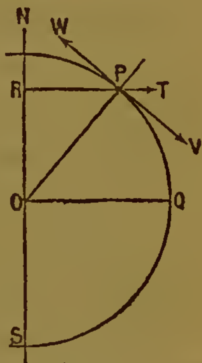


Fig. 1.

If OQ, Fig. 1, represents the equator, NOS the earth's axis, then the angle POQ is the latitude of the point P, and P is spinning round in a circle perpendicular to the plane of the paper, of which circle R is the centre and RP the radius. But if P is moving in a circle there must be a force acting in the direction PT, the so-called "centrifugal force," which tends to make the body at P leave its circle and go off at a tangent. Gravity is pulling towards the centre PO, and PT is evidently *not* "in a direction opposite to that of gravity." The gravitational force being always much greater than the centrifugal force, the body

will not fly off the earth altogether, but, as the forces are not balanced, it will move in a direction PV, towards the equator. By drawing the figure for different positions of P it can easily be seen that the tendency will be for movement towards the equator in all latitudes, whether north or south, except at the poles. At the equator itself PT is in a direction opposite to gravity and the centrifugal force merely makes bodies a little lighter in weight. At the two poles, the radius of the circle having diminished to nothing, PT becomes zero.

The question immediately suggests itself: Why, then, do bodies free to move not set off towards the equator on their own account? For the simple reason that the earth, fashioned originally by the interaction of these same forces, is not a sphere but (approximately) a spheroid in shape, the equatorial radius OQ being some thirteen miles greater than the polar radius ON or OS. The journey from either pole to the equator is consequently uphill, *i. e.* the resistance or support offered by the earth's surface is not exactly opposite to

the direction of gravity, and the down-hill force (PW in the diagram) is everywhere just sufficient to balance the equatorial force PV. This is, of course, the real table-top or horizontal plane. If the earth began to spin faster or slower than it does all free bodies would start to move equatorwards or polewards, unless, indeed, the shape were correspondingly altered to readjust the slope.

Coming next to bodies not at rest on the earth's surface, but moving on it under the action of some independent force—such bodies as railway trains, bicycles, moving masses of air or water—we take only the two simplest cases, those of motion eastwards and westwards. The earth spins round from west to east, and if a body is moving eastward it is merely spinning in its circle of latitude faster than the earth's surface is in that latitude. But, referring again to Fig. 1, if the rate of rotation increases the centrifugal force PT (and consequently PV) is increased. The shape of the earth is not altered to suit the new conditions, and the upward slope to the equator is now not steep enough to balance the increased

centrifugal force. Hence whenever a body begins to move eastwards a new force comes into play, and a tendency to leave the eastward direction and move towards the equator appears.

Similarly, a body moving westwards is simply spinning in its circle of latitude slower than the earth's surface in that latitude; the centrifugal force is accordingly diminished and no longer suffices to balance the tendency to roll down towards the pole. The new force therefore acts polewards.

In the northern hemisphere the deflection equatorwards of an eastward-moving body and polewards of a westward-moving body is a deflection towards the right in both cases; and in the southern hemisphere it is a deflection to the left. It would be somewhat beyond the scope of this book to show that the deflection takes place independently of the direction of the original movement: we content ourselves with the mere assertion, and lay down the following rule: *Every body moving on the surface of the earth is deflected to the right in the northern hemisphere, and*

to the left in the southern hemisphere, because of the earth's rotation. This generalization, which is now usually known as Ferrel's Law, is of great importance in meteorology. Let it be clearly understood that the rotation of the earth cannot set up or maintain movement on its surface: the action is wholly that of deflection of a body, set in motion by some other force, from the path it would follow if that other force were acting alone.

For the purposes of meteorology the nature of the surface which receives or gives off radiation is of fundamental importance. The surface of the earth may be regarded as made up of three distinct kinds—Land, Water, and Ice. It will be well to examine the physical properties of these separately.

Land surface, which includes the exposed surfaces of all rocks and the soils derived from them, has the universal characteristic of being opaque to rays of all wave-lengths. Hence all rays coming from the sun are at once stopped or absorbed, and their energy converted into heat. The warming effect of

the heat received at the surface in this way depends upon (1) the quantity of heat required to warm a given quantity of the material forming the surface through a given range of temperature, *i. e.* its "specific heat," and (2) the rate at which the heat is transferred to layers below the surface, *i. e.* its "conductivity." Different kinds of rock and soil material have different specific heats and conductivities, but it is found that the texture rather than the substance of the material is important, for a loose dry soil, like sand, contains a large quantity of air (one of the worst of heat conductors, as every wearer of loose clothing knows) and therefore conducts heat slowly; while a compact soil like clay, more especially if it be water-logged, conducts heat with comparative ease. Thus in a dry sandy desert the heat received at the surface is concentrated at that surface and the temperature rises very high, while with a clay soil much of the heat is distributed to layers below the surface almost as fast as it is received, and the surface remains comparatively cool.

Similarly, when radiation takes place from

the surface of sand the loss of heat is not made good from the under layers, and the temperature falls very low: but in clay a supply of heat is kept up from below. Shortly, we may say that if a soil contains much imprisoned air the range of temperature at the surface will be great, and if it is close in texture or moist the temperature range will be small. Evidently the matter is one of great significance in connexion with questions of agriculture as well as of pure meteorology.

The thermal arrangements over a surface of water are very different from those on the land. To begin with, rays falling upon water are not all stopped at the surface, water being to some extent transparent or diathermanous. Absorption, and therefore heating effect, takes place gradually from the surface down to quite considerable depths: but it may be assumed that the layer in which serious changes of temperature occur in this way is very shallow, and that to all intents and purposes the peculiarity may be ignored. Next, and much more important, is the very high specific heat of water, which enables it

to absorb and give off enormous quantities of heat while undergoing only small changes of temperature. The importance of this in reducing the range of variation of temperature over a sea surface as compared with a land surface is fundamental, and is not infrequently very much under-estimated. Lastly, the change in specific gravity of water produced by change of temperature must be considered. In the case of sea water it may be said quite generally that warm water is lighter than cold, so that when surface water is warmed it becomes lighter and tends to remain at the surface, while if it is cooled it becomes heavier and tends to sink and be replaced by warmer water from below. Thus the general influence is to keep the sea surface warm. Variations in the salinity of sea water complicate the conditions actually occurring in the oceans, and the temperature effect is often difficult to trace. In fresh water we have the further peculiarity that the temperature of greatest density is about 39° F., the water becoming lighter as it is cooled below that temperature to the

freezing point, as well as when it is warmed above it.

A large part of the earth's surface in high latitudes is more or less permanently covered with ice and snow, and it is to be noted that, from a meteorological point of view, this to a great extent obliterates the difference between land and sea, inasmuch as it forms a uniform covering having the same physical properties. Snow usually contains a large amount of imprisoned air near the surface, and is in consequence a bad conductor of heat. Hence it resembles a dry sandy soil as regards range of temperature, with the limitation that the temperature cannot rise above the melting point. Down to comparatively low latitudes large land areas are covered with snow during the winter season, a most important consequence being delay in warming up the surface in spring on account of the vast quantities of heat absorbed in melting the snow and ice and then evaporating as much of the resulting water as is not drained off or absorbed.

In dealing with differences of temperature

arising between different kinds of surface, it is essential to observe that these arise in consequence of different *rates* of heating and cooling, and will be greatest when these rates are greatest. We have already pointed out that the maximum differences between day and night temperatures occur in low latitudes; hence the greatest diurnal differences between land and sea, due to the more rapid heating and cooling of the land, will be met with near the equator. On the other hand, the seasonal variations of temperature in low latitudes are small: and since the changes are small the difference in temperature between land and sea cannot be great at any season. It might be supposed that the seasonal difference described would increase with the latitude until the pole is reached (see above, p. 20), but as a matter of fact this is not the case, partly because although the sun is continuously above the horizon for a long time in high latitudes, its altitude is so small that its rays do not attain great intensity, and partly because, as already explained, the distinction between land and sea surfaces is to some extent

obliterated by the permanent covering of ice and snow. The greatest seasonal differences of temperature between land and sea are in fact found in intermediate latitudes, where the rays of the summer sun are intense, and where the sea always presents a surface of water. The positions and outlines of the great land areas, and the action of the atmosphere itself, also exert great influence in determining the positions of these areas of maximum difference.

CHAPTER II

THE ATMOSPHERE: ITS PHYSICAL PROPERTIES

PASSING now to the examination of the atmosphere and of the conditions imposed upon it at the earth's surface, we have at once to recognize its dual nature. It consists of a mixture of substances all of which, with one exception, are in the condition known as gaseous; the exception being water substance, which is present in the form of vapour.

The properties of gases and vapours are of course to be fully studied in text-books of physics, but it may be well to emphasize here some points which are of special importance for our purpose.

Imagine a closed vessel, the larger the better, to be absolutely dry and exhausted of all ponderable matter. Then suppose the minutest imaginable quantity of a gas to be admitted. It is the property of all gases that,

no matter how large the vessel, or how small the quantity admitted, the gas will expand until the whole vessel is filled, and in a continued effort to expand still further, will press or exert *pressure* upon the walls of the vessel. [This force or pressure can be measured in terms of a weight on a given area—so many pounds per square inch, kilograms per square centimetre, and so on.] Now let another quantity of gas, equal to the first, be admitted. This second instalment will also proceed to expand, and exert its pressure, independently; the pressure being now doubled. This process can be continued indefinitely, the only limitation being that imposed by the strength of the vessel.

We have here supposed, to begin with, that the small quantities of gas admitted to the vessel at first were able to expand in filling it. But this process of expanding, or increasing in volume, means an expenditure of energy or the doing of a certain amount of work, and we have to observe that the energy can only be obtained from within the gas in the form of heat. In expanding, heat is "used up,"

and the gas becomes colder. It may be supposed that at a later stage of the proceedings the pressure in the vessel being filled becomes greater than in that from which the supply is being obtained, and that consequently, it must be forced in or compressed. Instead of the gas doing work to expand itself, work must now be done upon the gas to compress it; the consequence is that work is converted into heat and the gas is warmed. This second fact is familiar to every one who pumps up a bicycle tyre, and in so doing observes that the farther end of the pump barrel becomes hot to hold; the first, and for obvious reasons less familiar, fact can be discovered by unscrewing the valve of the inflated tyre and holding the hand in the cool stream of escaping air.

We note for future use that a gas will (1) escape if possible from a place where its pressure is greater to one where it is less; (2) become heated if it is compressed; and (3) become cooled if it is allowed to expand. These statements are true, and equally true, for all gases and mixtures of gases, irrespective

of their chemical composition. The gaseous atmosphere enclosing the earth consists of a mixture of nitrogen and oxygen, with small quantities of carbonic acid and traces of rarer elements. The proportions of this mixture, or air, are sensibly constant throughout the lower atmosphere, and indeed, through all those parts of the atmosphere which we have to consider. Recent research has shown that the composition is somewhat different at great elevations.

The properties possessed by aqueous vapour will perhaps be best described by referring again to the dried and exhausted vessel. Suppose now that instead of gas a minute quantity of water, in the liquid state, is admitted. The liquid will immediately on entering the vessel change its state or evaporate, becoming to all intents and purposes a gas, filling the whole vessel and pressing upon its walls just as the gas did. A similar fate will in all probability befall the next drop of liquid, and the result as to pressure will be the same. But, and here comes the difference between a gas and a vapour, the process

cannot be eontinued indefinitely; it will go on until *a certain maximum pressure is reached*, and beyond that no addition of liquid will have any effeet upon the pressure, which will remain at its maximum; added water will simply colleet in the liquid state at the bottom of the vessel. Experiment shows that this maximum pressure dcpends upon the temperature and the temperature only; the maximum possible pressure inereases with the temperature, and that at an inercasing rate.

Vapour which is below the maximum pressure possible at the temperature existing at the time, is said to be *dry*, and the drier vapour is the more elosely it eorresponds in its properties to a gas. If a free surfaee of water is exposed in the presence of dry vapour, evaporation will take plaee and the pressure of vapour inerease till the maximum possible for the temperature is reachcd, when the vapour is said to be *saturated*. Any mass of dry vapour in the absenee of liquid water ean be saturated by simply eooling it till the temperature reaches the point at whieh its pressure corresponds to saturation. If the

temperature is still further reduced, then the pressure is greater than that of saturation at the new temperature, and vapour is *condensed* or returned to the liquid form until the pressure is reduced to the corresponding point of saturation.

The following table of saturation pressures, originally due to the experiments of Regnault, will help to make this clear. Temperatures are given in the first and third columns, and in the second and fourth columns will be found the saturation pressures expressed (for reasons to be explained presently) in "inches of mercury" (p. 51).

Temp. F.	Saturation pressure, inches.	Temp. F.	Saturation pressure, inches.
2°	0·048	62°	0·556
12°	0·074	72°	0·785
22°	0·118	82°	1·092
32°	0·181	92°	1·501
42°	0·267	152°	7·940
52°	0·388	212°	30·000

Suppose the pressure in a given mass of vapour is 0·181 inches of mercury, then the mass will be saturated if the temperature is

32° F. If cooled down to (say) 22°, condensation will take place until the pressure is reduced to 0·118 inches. If instead of cooling below 32°, we raise the temperature above that point, then in the absence of further supplies of vapour from a liquid surface the pressure remains at 0·181 inches and the vapour becomes dry. Under these conditions the existing pressure of vapour (in this case 0·181 inches) is called the *absolute humidity*, and the temperature corresponding to saturation, *i. e.* the temperature to which the mass of vapour would have to be cooled down (in this case 32°) in order to saturate it, is called the *dew-point*. It is convenient to have a means of expressing the relation between the actual and possible amounts of vapour present under any stated conditions, as this gives, amongst other things, a measure of the dryness, and hence of the rate at which evaporation of moisture will take place. This is done by taking the ratio between actual and possible vapour pressures: the result (expressed in per cent.) is called the *relative humidity*. Thus in the case given above the absolute humidity

being 0·181, if the temperature is 32°, then the ratio of actual to possible is unity or the relative humidity is 100 per cent., or saturation. If the temperature is 42° the ratio is $\frac{181}{267}$ or 68 per cent.; if 72°, $\frac{181}{785}$ or 23 per cent., and so on.

Calculations like these, or their results, are to be found in the weather reports of many daily papers. It is important to understand clearly the meanings of the terms saturation, dew-point, absolute humidity, relative humidity.

Since the source of water vapour is the liquid or moist surfaces on which the atmosphere rests, and since, as we shall see, temperature usually falls rapidly with increasing elevation, we are not surprised to find that the bulk of the water vapour in the atmosphere is in the lower strata.

From what has been said, it will be apparent that the study of the physical conditions of the atmosphere requires, in the first instance, observations of temperature, pressure and moisture. It is unnecessary to describe here the detailed arrangements commonly employed

for these purposes—they arc fully set forth in the official "Instructions" published by various authorities and in nearly all text-books of meteorology (see bibliographical note, p. 253), but there are some points requiring explanation in order to understand the methods used in discussing results.

With regard to temperature it is to be notcd that thermometers, adapted as may be neeessary to give continuous reeords, maximum or minimum temperatures, or merely the tempcrature at the instant of observation, are intended to measure the tcmperature of the air in their immediate neighbourhood, and they are therefore cxposed in such a manner as to have as free circulation of air as possible, and at the same time to bc protected from direet radiation. It being impossible to realize these conditions fully, the chief efforts are concentrated on obtaining uniformity of exposure, so that crrors are likely to be approximately the same in all cases. For land stations there is thc eonvention that thermometers shall be placed at a height of four feet above the ground.

Where observations are to be used for the purpose of forecasting the weathcr the temperatures over the area concerned are recorded for a particular time (7 a.m. in the case of this country and Western Europe generally), but for nearly all other purposes the unit employed is the mean for the day of twenty-four hours. This value is obtained from continuous records, or averages of hourly observations, or by some device for calculating it indirectly from a small number of daily observations.

We have seen that there is no continuous heating or cooling at the surface of the earth, but that variations, periodic and irregular, are constantly taking place. Every point on the surface must therefore have a *mean temperature.* The distribution of temperature over the surface is most easily studied in terms of these mean values, and the variations both in space and time are conveniently treated as departures from the means. Let it be supposed, for example, that obscrvations of the daily mean temperature are made in the manner described, for

fifty years. The average of all these observations will represent the true mean temperature of the place with a considerable degree of accuracy, and we can compare the average for any one year with this standard, and say whether the year was hotter or colder than the normal. Similarly, we can group the fifty years' observations into months; we get approximate normal values for the temperature in January, February, March, etc., and comparing the mean for any month with the fifty-year average for the same month, we estimate the relation of that month to the normal. A comparison of a warm year, 1868, and a cold year, 1879, with the long-period average at Greenwich is given as an example in the following table—

	Jan.	Feb.	Mar.	April.	May.	June.
Mean (1841–1905) .	38·6	39·5	41·9	47·3	53·0	59·4
Year 1868 . .	37·6	43·5	44·5	48·7	58·0	63·2
,, 1879 . .	31·8	38·3	41·2	43·5	48·6	57·0

	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mean (1841–1905) .	62·7	61·6	57·3	50·0	43·5	39·9
Year 1868 . .	68·1	63·9	60·4	48·2	41·8	46·1
,, 1879 . .	58·2	60·2	56·3	49·3	38·5	32·5

The need for averages extending over long periods is due to the wide range of the irregular variations and the rare occurrence of the extreme values. Observations have been made continuously at Greenwich for seventy-one years, but a temperature of 100° F. was recorded for the first time on August 9, 1911, and near approaches are uncommon. In the seventy-one years' observations maximum temperatures of—

100° F.	were	recorded on	1	occasion.
97°	,,	,,	1	,,
96°	,,	,,	2	occasions.
95°	,,	,,	3	,,
94°	,,	,,	8	,,
93°	,,	,,	15	,,
92°	,,	,,	32	,,
91°	,,	,,	38	,,
90°	,,	,,	55	,,
89°	,,	,,	86	,,
88°	,,	,,	123	,,
87°	,,	,,	171	,,
86°	,,	,,	220	,, [1]

[1] I am indebted to Mr. W. W. Bryant, of the Royal Observatory, Greenwich, for the figures in the tables.

Thus it takes a long time for the irregularities to "cancel" each other. Speaking quite generally, we may say that, so far as air temperature at least is concerned, the irregularities are smallest in low latitudes.

When we come to compare temperatures in different places, *i. e.* to deal with the geographical distribution of temperature, graphic representation upon a map is necessary. In the first instance the temperature values, which must of course be strictly comparable amongst themselves (true means or values for identical periods), are simply "plotted" or written down on the map at the points to which they refer. Appeal to the eye is then made by a system of lines analogous to contour lines, each line passing through all points on the map having the same temperature. These *isothermal* lines require, strictly, an infinite number of stations if they are to be drawn accurately, but in practice (just as in the case of contour lines) it is assumed that the temperature varies continuously between any two stations, and that lines can therefore be drawn proportion-

ately between them. In the case given below, for example (Fig. 2), temperature values are plotted for the places indicated by dots, and the isothermal line of 35° is drawn although

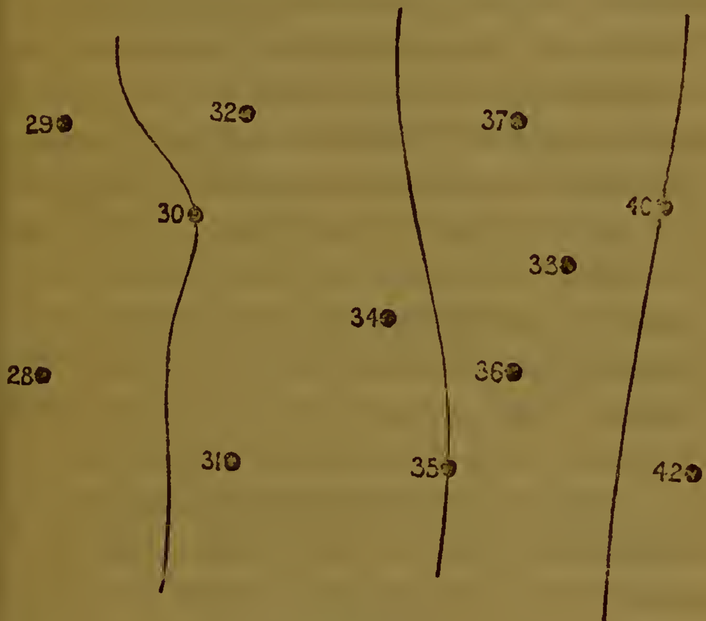


Fig. 2.

only one point of observation actually records a temperature of 35°. In reading maps of this kind it has always to be borne in mind that this system of interpolating lines introduces, at a very early stage, an arbitrary element of "interpretation" of the observa-

tions. Additional uncertainty arises from the fact that as the distribution of stations is usually very unequal, the lines are much less trustworthy in some parts of the map than in others. In the great atlas published in the Reports of the *Challenger* Expedition, the isothermals for India depend on ninety-eight stations, those for China on only twenty-one; but there is no known method of indicating the relative degree of accuracy of the lines upon the map of Asia. In rainfall maps, where the uncertainty is much greater than in the case of temperature, we have the British Isles represented by some 5000 stations, while it would not be difficult to find areas in South America larger than the British Isles from which we have no records at all—the "isohyctals" being drawn by a judicious play of the imagination upon the meagre data.

Useful as the graphic method of "iso" lines is, it can at once be converted into a much more powerful weapon by regarding the lines as the edges of surfaces meeting the surface of the earth. Any two surfaces meet

in a line, and we can think of the isothermal line as the line upon which an *isothermal surface* (a surface upon which the temperature is at all points the same) meets the earth. We can suppose an airman so directing an aeroplane in its flight that the temperature of the air through which he flies remains constant; he would travel about upon an isothermal surface, and if he alighted he would land at some point upon the isothermal line where that surface cuts the earth. Referring again to Fig. 2, we can imagine him on the isothermal surface of 35° F., east of the map, and at some elevation. As he goes westward the isothermal surface dips down, until it reaches the earth on the line of 35° F.

The student will find it well worth while to picture to himself the configuration of isothermal surfaces suggested by different forms of isothermal lines. The fact that lines far apart on the map—*i. e.* uniform temperature on the earth—indicate surfaces nearly horizontal, while lines crowded together—or steep temperature gradients on the earth—indicate surfaces greatly inclined, is specially

worth noticing. As an exercise, the dome-shaped surfaces over a hot area, and the saucer-shaped surfaces over a cold area, should be considered.

The pressure of the atmosphere is measured, in terms of weight, by means of the barometer. We again refer the reader to official publications, or to any of the modern text-books on meteorology, for an account of the construction of this instrument and of the corrections applicable to its readings. It is enough to explain here that, air being extracted from the inside of a glass tube which is closed at the upper end and hangs vertically, the pressure of the atmosphere forces mercury into that tube at its lower end until the force of the weight of mercury retained in it is just equal to that exerted externally by the atmospheric pressure. The total force exerted by the atmospheric pressure is proportional to the area upon which the force acts, *i. e.* to the cross-section of the tube. But the weight of mercury in the tube is also proportional to the cross-section of the tube. The height of the mercury

column is therefore independent of the bore of the tube, and as the weight of mercury in the tube is also proportional to the length of the column, this column gives a measure of the pressure exerted. For this reason it is not usual to reduce atmospheric pressures to such measures as pounds per square inch; they are expressed directly in terms of the length of the column of mercury. At sea-level the average atmospheric pressure is about 14·7 pounds per square inch, corresponding to about thirty inches of mercury. It may be pointed out that the use of mercury for the construction of barometers is chiefly one of convenience and portability. Water barometers can be and have been made, but mercury being 13·5 times as dense as water the column of the water barometer is 13·5 times as long—about thirty-four feet—reminding us that the common suction pump is merely a very imperfect water barometer in course of construction. Again, instruments of the "pressure-gauge" type, such as the aneroid barometer, are effective, except that their "zero" is arbitrary and apt to

change. Measurements made with a barometer of the type ordinarily used for scientific purposes are "read" to 0·002 ($\frac{1}{500}$) of an inch and are probably accurate to about 0·01 ($\frac{1}{100}$) of an inch.

All that has been said about the reduction and representation of temperature observations holds good with regard to pressures. The diurnal variation of pressure is remarkable in that, for some reason not yet fully explained, it usually has two maxima and two minima in the twenty-four hours, instead of the single maximum and minimum of the temperature curve. This double phase is of paramount significance in low latitudes, where the regular daily variations extend through a wide range, as great as that of many of the disturbances associated with tropical hurricanes; but in higher latitudes, as in the British Isles, the daily variation becomes so small compared with the irregular disturbances that it is only recognizable in mean values taken over long periods. The selection of an hour or set of hours for barometric observations is therefore chiefly important in the tropics, and in

temperate regions the observations are usually made at the times suitable for observations of temperature.

In pressure maps the isothermal lines become *isobaric lines* or *isobars*, which are usually drawn for every tenth of an inch (see Plates 3 and 4). *Isobaric surfaces* take the place of isothermal surfaces; their significance will be fully appreciated by any one who has mastered the general principle.

We shall see in what follows that the first great physical problem of the meteorologist is to describe and account for the circulation of the atmosphere. All questions of climate and weather are ultimately included in this, but we may go a step farther and say that all atmospheric circulation depends on differences of pressure, and all differences of pressure depend ultimately on differences of temperature, the relation of the one to the other being profoundly affected by the evaporation and condensation of water vapour. A knowledge of the distributions of temperature and pressure and of their variations is therefore

more important than anything else. Fortunately, we are now reaching a stage at which it may be said that a fair amount of such knowledge has been acquired.

Again fortunately, it seems likely that as knowledge of temperature and pressure distribution increases we shall, by careful interpretation of the results of laboratory experiment, some of which have already been stated in outline, be able to infer the chief facts about the distribution of vapour. These facts, as has been recently shown by researches into the theory of the matter, are of great complexity, and unluckily direct observation of the amount of moisture in the atmosphere is so troublesome that the supply of available data is still very small.

We may divide the possible methods of dealing more or less adequately with the question of moisture into three groups: (i) direct observation of vapour in the atmosphere; (ii) measurement of the vapour passing into the atmosphere, or evaporation; and (iii) measurement of water condensed out of the

atmosphere, or precipitation. The first constitutes the subject of hygrometry; the observations consist either of direct determination of the temperature of the dew-point by cooling a polished surface until moisture is deposited on it by condensation from the atmosphere, or else of indirect observations of such instruments as the dry and wet bulb thermometers. In the latter the wet bulb, cooled by evaporation of water from its surface, stands at a lower temperature than the dry bulb, the dew-point and relative humidity being calculated from the difference by means of tables. Direct hygrometers are troublesome and difficult to work. Dry and wet bulb observations have been made at a large number of stations for many years and the dew-points and absolute and relative humidities calculated, but it has always been tacitly assumed that so little reliance can be placed upon the results that little use has ever been made of them. It seems not improbable that in skilled hands the records may be made to yield fairly satisfactory information, but as yet no really serious attempt has been

made to discuss them, and little is known about the distribution of humidity.

The measurement of the amount of water evaporated from a surface of known area is also beset with practical difficulties of a serious kind, and consistent results are available from only a small number of isolated stations. Even supposing a satisfactory and easily worked evaporimeter to be forthcoming, its indications would be difficult to interpret correctly, for evaporation from an artificial water surface is one thing, and evaporation from a sea surface or from damp soil or growing vegetation quite another.

Precipitation occurs chiefly in the form of rain, and what is received in other forms is conveniently measured in terms of "rainfall." The general principle of the *rain-gauge* is that a known area—usually defined by an accurately turned brass ring having a sharp edge—is exposed so as to receive precipitation, and the water collected retained and its depth measured. Thus one inch of rainfall means simply rainfall sufficient to cover the area

considered with a layer of water one inch in depth, supposing none of the water to be lost by drainage or percolation. Here, given certain fairly simple precautions, comparable if not very accurate observation is easy, and the number of rainfall records to be had from most parts of the world, some of them extending over very long periods, is now very large. Rainfall is, of all the meteorological elements, the one which varies through the widest limits and with the greatest irregularity; hence a true value of average rainfall can only be arrived at after very prolonged observation.

Rain is primarily the effect of cooling a mass of vapour in the atmosphere below its dew-point. Condensation takes place first in the form of minute drops which float as visible masses called clouds, the type of cloud depending upon the manner in which condensation has taken place. As the process continues the cloud particles coalesce and form larger drops, and since the weight of a drop increases faster than the superficial area by which it offers frictional resistance

to falling, the drops no longer float in the air, but fall to the ground.

Many points connected with rain phenomena are still obscure, the most difficult being those relating to the part played by charges of electricity in condensation. But two things are clear: first, that the cooling which produces the condensation is in the great majority of cases due to expansion of the air with which the vapour is mixed (see p. 36); and second, that the condensation producing cloud particles takes place upon motes of impalpable dust which are found floating in the atmosphere even at great elevations. The reduction of pressure necessary to allow of expansion and consequent cooling may take place in a variety of ways, some of which will be considered later on; but it is remarkable that the condition of actual saturation is not frequently observed. Condensation in effect usually takes place in strata of the atmosphere which are some distance above the ground, and the rain *falls through* air which is slightly dry. Probably also the dust particles are to some extent hygroscopic, and extract

moisture before the point of saturation is reached. This is certainly often the case at sea, where the dust is known to consist largely of salt particles derived from spray; hence the familiar "dry fog."

CHAPTER III

THE ATMOSPHERE: THE CONDITIONS TO WHICH IT IS EXPOSED

In our first chapter we described in outline the conditions which would determine the temperature at the surface of the earth supposing there were no atmosphere, the conditions arising in direct consequence of the earth's position as a spinning ball revolving round the sun as a source of heat, and of the varying nature of its surface. We have since examined some of the physical properties of the atmosphere itself. The next step is to place the atmosphere in position, as it were, and to see how it behaves under the known terrestrial conditions.

In order to work from the simplest possible conditions, let us suppose, for the moment, that the earth is at rest, *i. e.* without rotation, that the rays of the sun are cut off, and that

the surface of the earth is uniform—all level land or all sea. We may then assume that the temperature would be the same in all parts. Leaving the atmosphere of water vapour out of consideration for the present, suppose that a minute quantity of air is set free at the surface. This air will spread itself evenly in a uniform very thin layer over the whole surface, being held on by the force of gravity. It will rest upon the earth, in fact, by its own weight, and since from the nature of a gas the pressure at any point must be the same in all directions, there will be a certain pressure due to the weight of the air, and measurable by the barometer, throughout the whole mass. The pressure must evidently be the same at all parts of the earth, for if it were not air would move from places where it was greater to places where it was less (see p. 36) until equality ensued. Now suppose a second supply of air to be set free: this air might be supposed to place itself in a second thin layer outside the first, its arrangement becoming in every way similar. But note that the first layer has now to bear the weight

of the second, which is resting upon it. The first is therefore subjected to increased pressure, but as before the pressures must be the same at the same levels throughout, otherwise there will be horizontal motion.

If this process is continued indefinitely until the quantity of air set free is equal to the amount actually present in the atmosphere, we shall then have an atmosphere at rest, the pressure being the same at all points of any horizontal plane, but diminishing with elevation from the surface of the earth upwards. In other words, the isobaric surfaces will be horizontal, forming concentric or confocal shells round the earth like the coats of an onion. As the isobaric surfaces (being horizontal) are parallel to the surface of the earth, they do not cut it, and hence there are no isobaric lines.

Under the conditions described the isobaric surfaces representing equal differences of pressure would be farther apart the higher up we went in the atmosphere, because, the actual pressures being less, the density of the air would be less : that is to say, if pressure at

sea-level is 30 inches and we have to ascend 450 feet to reach the isobaric surface of 29·5 inches, we shall have to ascend rather more than 900 feet from sea-level to attain the surface of 29·0 inches, and so on.

With the limitations imposed, it may be imagined that the temperature of the atmosphere would be uniform throughout, but if we supposed it to be warmer near sea-level and colder in higher altitudes, the result would still be the same provided always that temperature was the same all over the earth's surface and the rate of fall with increase of height everywhere the same, *i.e.* that temperature was the same at all parts of any isobaric surface or horizontal plane; the effect would merely be to alter the density of the atmosphere at certain levels and so to change the distances between the isobaric surfaces at different levels.

To sum up—*the pressure of the air in the atmosphere diminishes from below upwards, and the condition of rest is that the isobaric surfaces shall be horizontal.*

By assuming that these conditions are

actually realized, the barometer is often used to obtain approximate measurements of the heights of mountains. Let A, Fig. 3, be a point at "sea-level," and let B represent the summit of a mountain, shown in section. The lines 30·0, 29·0, 28·0, are the edges of the isobaric surfaces. If we know the temperature conditions, we can, by using a suitable

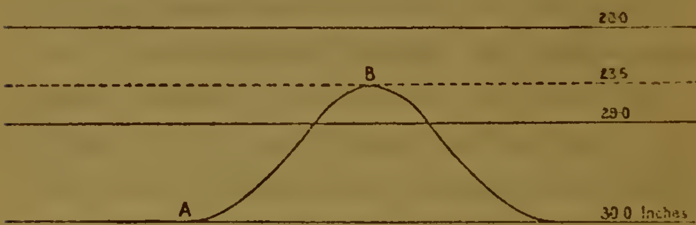


Fig. 3.

formula, calculate the heights of those isobaric surfaces, or of the one (28·6) which passes through B. If the isobaric surfaces are horizontal (and not otherwise), the horizontal distance between A and B does not matter, and the vertical distance is thus known from the difference of barometer readings. The inaccuracy of the method in practice arises from the difficulty of realizing the condition that the isobaric surfaces shall be horizontal.

In the upper atmosphere, above heights of nine or ten miles, the mixture of gases forming the "air" is of very different composition to that with which we are familiar. Probably it consists almost entirely of hydrogen, the existence of which can scarcely be detected in ordinary air. Considerable speculative interest attaches to the final upper limit of the atmosphere, the isobaric surface of zero pressure, which must exist somewhere. Below this level there must be "air" of some sort, and above it only the ether. The isobaric surface represents a free surface of gas, a phenomenon entirely outside our experience: we cannot think of a bottle half full of gas.

The condition of rest being established, it is easy to see that the condition of atmospheric motion is that the isobaric surfaces should not be horizontal, but inclined. Let Fig. 4 represent a section through a part of the atmosphere, the lines indicating edges of isobaric surfaces as in Fig. 3, and let it be supposed that from some cause the surfaces 29·9 and 29·8 are higher in one part (to right of the diagram) than in another (to the left).

Then at A and B, A′ and B′, pairs of points in the same horizontal planes, pressure is greater at BB′ than at AA′, and air will flow from BB′ to AA′. Where the surfaces are inclined in the lower strata of the atmosphere they will probably cut the surface of the earth, upon which there will therefore be represented isobaric lines. Hence we

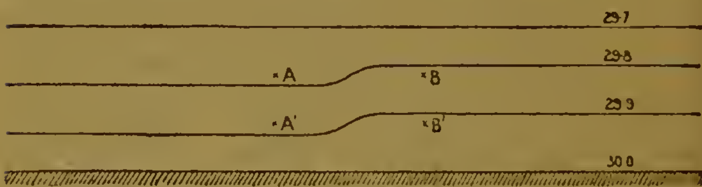


Fig. 4.

have, generally, the result that horizontal motion of the atmosphere, or wind, occurs when the isobaric surfaces are tilted, and that surface winds are associated with differences of pressure on the ground-level, which are represented by isobars. Obviously the greater the difference of pressure in a given distance (as AB) the more the isobaric surfaces are tilted, and if they cut the earth's surface the closer the isobars will be together. Since the strength of the wind depends on

the difference of pressure in a given distance, or (as it is called) the *barometric gradient*, isobars close together will evidently be associated with strong winds, and conversely.

The important element here being difference of pressure *in the same horizontal plane*, barometric observations made at different places must be cleared of any difference arising from places not being at the same level; it would be useless, for example, to compare readings made at A and B (Fig. 3) directly for the purpose of ascertaining the form of the isobaric surfaces. In this case the height of the point B above A would be determined independently by levelling or other precise method, and the formula already referred to would be used in reverse—"given the difference in height, what is the normal difference of pressure?" In this way the reading at B is "reduced" to the level of A, and a residual difference between the two readings, if there is any, is regarded as due to real disturbance of the isobaric surfaces. For practical purposes barometer readings are always reduced to sea-level; thus in charts

showing distribution of pressure (as Plates 3 and 4) the isobars do not show the actual pressures observed at different places, but the pressures as they would have been if all the places had been at the level of the sea. The lines accordingly represent the real edges of the isobaric surfaces, or the barometric gradients.

We have now to connect differences of pressure with differences of temperature in such a way as to show that, given differences of temperature, differences of pressure will necessarily arise. This is most easily done by reference to isobaric surfaces. Consider a part of the earth's surface over which the atmosphere is in the condition of rest, *i. e.* the isobaric surfaces are horizontal. Let a part of this be enclosed by a chimney of any sectional area, and let it be supposed that the air within the chimney is raised through its full height to a temperature higher than that outside. The enclosed air will then expand so that while its total weight (represented by the pressure at sea-level) will remain unaltered, the vertical pressure

gradient will be diminished; pressure will fall more slowly with increase of height and the isobaric surfaces will be farther apart. This means, of course, that at any level (above sea-level) pressure will be greater inside the chimney than outside it in the same horizontal plane. If the barrier of the chimney be now removed, air will flow out from the central warm area at the upper levels in all directions towards the surrounding colder region. But in consequence of this, the total weight of air resting on the warm area is diminished, and that on the cold area increased. The sea-level pressure is therefore less than before in the former area and greater than before in the latter, and so air will flow inwards at the lower levels. The inflowing air, becoming warmed in its turn, will ascend to take the place of the air flowing out above, while the outflowing air will descend to supply the deficiency in the low-level outside ring. A steady state will eventually be established, in which the isobaric surfaces will take somewhat the form shown in section in Fig. 5.

The arrows show the direction of the

vertical circulation, which is simply that of a convection current, the movement recognizable in a flask of water when the water is warmed. It has been thought desirable to give this analysis at some length (following Ferrel, *Popular Treatise on the Winds*, q. v.)

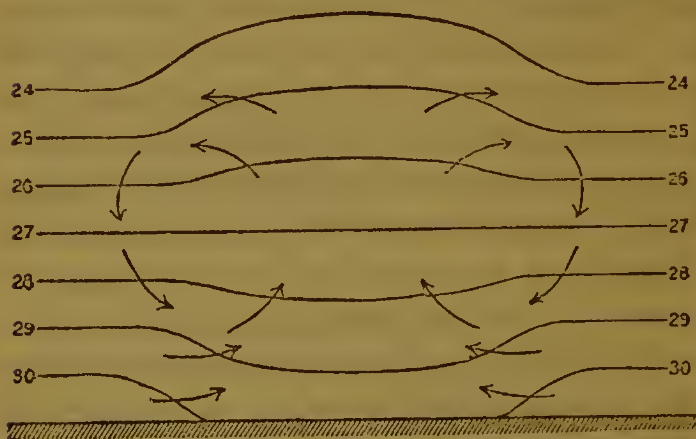


Fig. 5.

in order to establish fully the significance of the isobaric surfaces in a simple case before proceeding to use the method in the more complex cases which have to be considered presently. Note specially the central area of relatively low pressure at low levels, the similar central area of high pressure above,

and the neutral zone between, where the isobaric surface remains flat and horizontal, and the air movement is wholly vertical.

If we introduce a quantity of water vapour into the atmosphere in the case just described we find the conditions altered by the vertical movements. The air ascending in the central column is moving from a place of high pressure to one of low; that descending in the surrounding area is moving from a place of low pressure to one of high. (Observe that there is here no infraction of the general rule, p. 36.) Hence the ascending air is expanding and therefore cooling, while the descending air is being compressed and therefore warmed. If the air in the central column is fairly charged with moisture to begin with, as it may be if it rises from the surface of the sea, the expansion presently cools it below the dew-point and condensation sets in. But this sets free immense quantities of heat, which go to warm the air and so to strengthen the ascending current. The descending air, on the other hand, starts from a region where temperature (and therefore vapour content)

is low, and where there are no supplies of moisture obtainable. This current is therefore dried by the warming produced by compression, its relative humidity when it reaches the earth's surface may be extremely low, and it contributes nothing by condensation to the energy of the circulating system. We find, in fact, that where there are ascending currents the conditions are moist and rainy, and the winds (the horizontal movements) may be strong; with descending currents there is great dryness and the winds are usually relatively weak.

We leave the alternative case, that of the circulation arising from a cold central area surrounded by a region of higher temperature, to the ingenuity of the student, and proceed to the larger problem, which may be stated in these terms: the condition of the atmosphere remaining at rest being known, and the nature of the movement set up as a result of unequal temperature being known, what is the actual distribution of temperature in the atmosphere, and to what extent can the circulation (so far as it is known) be explained

as a consequence of that distribution? This amounts to modifying the imaginary conditions laid down on p. 60 to the extent of giving the earth its proper motions and establishing it in its true relation to the sun as a source of heat. We retain the condition of a uniform surface for the present.

As the sun's rays pass through the atmosphere on their way to the surface of the earth, they suffer little diminution at first, the clear dustless and vapourless regions of the upper strata being, so far as is known, almost perfectly transparent to rays of all wave-lengths. When the rays reach the lower strata, however, considerable absorption takes place. A certain proportion is stopped by the suspended particles; some are reflected backwards and forwards from one to another, giving the effect of *scattered* light, the light by which the sky is illuminated and all varieties of light and shade produced: others are absorbed by the mass of the particles, their energy is converted into heat, and the particles are warmed, the warmth being in part communicated to the atmosphere by

contact. Absorption of this kind does not take place equally with all rays, those of short wave-length being absorbed and scattered to some extent even when the suspended particles are relatively small and few in number. This is one reason why the sky is blue in colour, the upper atmosphere being chiefly illuminated by blue rays. When the particles are more numerous, or larger, it may be through adherent moisture, some rays of longer wave-length are absorbed or scattered, green and perhaps some yellow rays are added to those illuminating the sky, which then appears of a whitish sickly colour. Under such conditions only red light rays penetrate directly to the earth's surface, and the sun accordingly appears red. This *selective* absorption, which takes place when the suspended particles are increased in size by condensation, gives rise to many phenomena which have been utilized in forecasting weather—the amount of condensation producing them being commonly followed by more, ending in clouds and rain—and incidentally it is responsible for the

extraordinary failure of the light from the electric arc (which is specially rich in blue rays) for lighthouse purposes in hazy weather, as compared with the light of gas or oil lamps, which has a larger proportion of yellow rays. When actual cloud is formed the direct rays are almost entirely stopped, the upper surface of the cloud acts as if it were the surface of the earth: radiation from the earth (except to the under side of the cloud layer) is also cut off, and the atmosphere between earth and cloud is illuminated by scattered light alone.

Since, for the reasons already explained, most of the suspended dust particles and the greater part of the water vapour in the atmosphere are restricted to its lower layers, it follows that absorption and radiation, and the temperature effects due to them, occur chiefly near the surface of the earth; the importance of this element diminishes rapidly as we ascend. Observation shows that, on an average, about half the radiant energy from the sun is absorbed by the atmosphere, the remainder reaching the earth's surface directly. What happens to the rays on reaching the earth

has already been described. The layer of air in contact with the surface gains or loses heat by conduction; if its temperature is raised above that of air resting immediately upon it, it rises by convection and its place is taken by colder air, which in turn is warmed and rises; if, on the other hand, it is cooled by contact it becomes heavier, and retaining its place may ultimately assume the same low temperature as the surface on which it lies. Thus it appears that the temperature of the atmosphere is primarily controlled by the sun's influence acting at and near to the surface of the earth. That influence extends indirectly, through convectional or other movement, to an elevation which differs in different regions and varies at different times, but is somewhere in the neighbourhood of nine miles above the level of the sea. Beyond that height it would seem that the influence of the variations of temperature near the sea-level is scarcely felt.

The discovery that at heights greater than about nine miles the temperature, although it varies somewhat from place to place, remains

nearly constant at about $-70°$ F. at all levels, is one of the great achievements of recent meteorological research. In this "isothermal layer," or "advective region" as it has been called, there would seem to be comparatively little movement: the atmosphere, which in this region is practically free from water vapour, appears to float upon the under layer and to take no active part in its circulation. An important effect of this want of mixing movement is that the composition of the "air" changes quickly with increase of elevation. The percentages of oxygen and nitrogen diminish to vanishing point, and in the highest levels of all there is probably little trace of any gas except hydrogen (p. 37). The present state of knowledge permits us, in what follows, to leave the isothermal layer out of account, and treat the atmosphere of the under layer and its movements as if the advective region did not exist.

In this lower layer, then, temperature being determined by action originating at or near sea-level, there is normally a vertical tempera-

ture gradient, the temperature falling as we ascend until the 9-mile limit of altitude is reached. This gradient is, of course, subject to wide variation, and it may even be reversed, as not infrequently happens over areas where the earth's surface is cooled to very low temperatures by excessive radiation. It is altogether independent of the vertical gradients which occur in ascending or descending currents as the result of expansion or compression, or the condensation of vapour due to changes of pressure; and, indeed, the fate of an upward or downward current probably depends largely on the vertical temperature gradient in the air which surrounds it. In a rapidly ascending current of unsaturated air, for example, the rate of cooling due to expansion is 1° F. for every 178 feet of ascent. Suppose the ascending current to be convectional, due to the air at or near sea-level being 5° F. warmer than in the surrounding regions, then if at the time the normal gradient of those surrounding regions is 1° F. for every 200 feet of ascent, it follows that at a height of about 8,000 feet

the temperature is the same both inside the column and round about it, and the ascending force due to the difference is lost. On the other hand, if the normal gradient is more rapid than 1° in 178 feet the convectional action becomes stronger the higher we go. The expression "normal gradient" suggests the influence of elevation upon temperature in the case of mountains and raised lands generally, but this will be more conveniently dealt with later on.

In an earlier chapter we discussed (p. 19) the conditions which caused the sun's rays to fall with different intensity and for different periods on different parts of the earth's surface. The general results upon the atmosphere at sea-level will be readily understood from a consideration of those in relation to the atmospheric conditions just described. The temperature of the air is, on the average for the whole year, highest in the neighbourhood of the equator, and it falls as latitude increases both to north and south until the poles are reached. Average values for each month

show that the thermal equator, which maintains a nearly constant temperature, swings north and south, following the sun, but that, as the atmosphere heats and cools somewhat slowly, the swing extends through only a few degrees of latitude (the sun moves through 47 degrees) and the maximum departures north and south are delayed to a considerable time after the solstices. Also in both hemispheres the dates of maximum and minimum temperatures occur some time after the sun attains its highest altitude. These facts can be verified by examining isothermal charts for the months and the year for a part of the world where the condition of uniform surface (which is still imposed) is most nearly realized, *e. g.* along the meridian of long. 160° W. in the Pacific Ocean. (See Plates 1 and 2.)

Thus we have at all times a temperature gradient from near the equator towards the poles, the axis of constant maximum temperature migrating northward and southward, and the steepness of the temperature slope on either side changing with the seasons.

CHAPTER IV

THE PLANETARY CIRCULATION OF THE ATMOSPHERE

It being now understood that the position of the earth with regard to the sun produces a temperature gradient which, on the average, follows the parallels of latitude, and that this gradient must give rise to a certain circulation, we are able to investigate some aspects of this circulation in different zones. Since we still retain the assumption that the surface of the earth is uniform as far as thermal properties are concerned, it is evident that the circulation in question will not be established over the whole globe in its simplest form. It may nowhere be quite fully developed, but we shall expect to find that wherever the surface of the earth is uniform over large areas or through wide stretches of longitude, as in the great oceans, it will assert itself as the

normal type of circulation. This is, as a matter of fact, what occurs, and the value of the method consists in this, that we can take a fairly simple type of zonal circulation as a standard and regard the departures from that standard as disturbances due to the irregular distribution of land and sea. The planetary conditions follow definite laws which we may one day be able to subject to rigorous mathematical investigation, while the distribution of land and sea surface is irregular, and we are therefore conveniently working from the simpler to the more complex, so far as the main features are concerned. This standard system is appropriately called the Planetary Circulation.

In reading the following attempt to describe the planetary circulation the student must bear in mind that the course of research necessarily leads from the complex phenomena which are under observation towards the simple elements of which they are made up. Scientific inquiry constantly seeks the simplification of the subject investigated, and in the wider matters at least the easiest path for the

learner is from the simplest position available at the time, *i. e.* that most recently attained by research, backwards to the point from which investigation began. This seems almost the only path open to us here, but it must be understood that, until scientific knowledge has attained something approaching completeness, the principal scene of operations at any one time must be marked by all the features of a work in progress—temporary expedients of all kinds, here and there mistakes and misunderstandings, and even confusion. We have tried, in what follows, to give a fair statement of knowledge as it now stands, and admit frankly that the explanations proposed are often incomplete, and may sometimes be altogether erroneous. They will at any rate show how the inquiries have been carried on, and what stage they have reached.

Temperature being highest near the equator, and falling towards the poles on either side, it follows that the layer of atmosphere affected extends to a greater height in equatorial latitudes than elsewhere. Hence there is, in the upper part of this layer, a down-hill

flow of air towards the poles, and this must result in a fall of pressure over the equator at the surface of the earth, and a consequent ascending movement and inflow of air towards the equator from each side. Similarly in high latitudes the tendency must be towards increased pressure and downward movement to complete the convectional circulation. We have in fact a double system of convection currents, uniting in a ring of ascending air near the equator, and forming a hemispherical shell on each side in which the air moves poleward in the upper part of the layer and towards the equator at or near the earth's surface. It is important to note here that half the area of a sphere is included in the belt between 30 degrees north and south of its equator; and also that ascending currents from the earth's surface are usually strengthened by heavy condensation and consequent liberation of heat.

This circulation, simple at first, is at once complicated by the influence of the earth's rotation. The first effect is to deflect all horizontally moving currents to the right in

the northern hemisphere and to the left in the southern hemisphere. The poleward-moving upper currents are turned to the east (*against* the direction of the earth's rotation) and the under currents moving towards the equator are turned to the west (*with* the rotation); thus the upper winds are westerly, and at the surface we have north-east and east winds north of the equator, south-east and east winds south of it. But there is a secondary effect of a more complex character. The upper currents, moving eastwards and at the same time polewards, are following a spiral course towards the poles. As the radius becomes smaller and smaller with increasing latitude the velocity of movement, unhindered by friction against the rough surface of the earth, becomes very great, perhaps as much as three to four hundred miles an hour. With this high velocity in a nearly circular path there is developed great "centrifugal" force, tending to drive the air back to the equator; and the result is a struggle of the "pull devil, pull baker" type—the temperature action trying to send the air to the poles, and the centrifugal

force, generated by the temperature action and the effect of the earth's rotation together, trying to drive it back to the equator. The result is, in the end, of the nature of a compromise. The air ascends in a belt extending through 30 degrees of latitude on each side of the equator, the ascending movement being strong in the central zone and weak towards the outer margins; and the descending movement takes place in latitudes outside this belt. The quantity of air ascending must, on the whole be equal to that descending, hence the areas of ascent and descent are approximately equal. Again, a mass of air moving westward must exert (by friction) a certain turning force upon the earth which would change its speed of rotation, and this must be balanced by an equal force due to air moving eastward. That is, the turning power of east and west winds upon the earth must be on the whole equal. The east winds being mostly nearer the equator have a greater "moment" or "purchase," and they need not therefore be so strong.

Lastly, the westward-moving air in the

belts between latitudes 30° N. and 30° S. is (except at the equator) deflected poleward, and the eastward-moving air in the two areas of higher latitudes is deflected towards the equator. There is in effect a pressing of the air both from equator and pole towards the regions of 30° N. and 30° S., and so we have two belts of maximum atmospheric pressure in about those latitudes. Pressure becomes less towards the equator, both because of the temperature gradient and consequent convectional movement and because of the action of the force due to the earth's rotation: towards the pole the temperature gradient would tend to make it increase, but the deflecting force causes it to diminish. The belts of maximum pressure naturally form the principal areas of descending air, and their positions on the earth's surface are marked by belts of great dryness: they include nearly all the permanent dry deserts.

An examination of a map showing the observed average distribution of atmospheric pressure (at sea-level) for the year shows that the facts agree with the description just given,

the only serious discrepancy arising in the polar regions, where the mean pressure is somewhat higher than might have been expected. The diminution from the high-pressure belts is arrested between the sixtieth and seventieth parallels, and observations from higher latitudes indicate a rise rather than a fall beyond. This anomaly can probably be accounted for by reference to the greatly diminished power in high latitudes of the deflecting force due to the earth's rotation, and to the exceptional conditions which arise in a region wholly covered by rough ice. In any case it cannot be said of itself to invalidate the general explanation (substantially that originally due to Ferrel) of which we have given an outline.

The circulation in the upper part of the lower atmosphere having modified the distribution of pressure at the surface, we find that the movements of air in the under part, next the earth, are controlled by that modified pressure distribution, and hampered in many ways, especially (fortunately for us) as regards speed, by friction. For it must be under-

stood that the earth's surface offers great frictional resistance to air movement—as is evident from the rapid growth of sea-disturbance through the action of wind—and the higher speeds are only attained where one layer is able to slide upon another. The chief regions of vertical movement—the equatorial low-pressure belt and the two high-pressure belts—are regions of calms, *i. e.* of little horizontal movcment. From the high-pressure belts winds blow from north-east and south-east towards the equator, and polewards (but again deflected eastward) from the south-west and north-west.

The equatorial low-pressure belt and the "sub-tropical" high-pressure belts swing with the seasons in a similar manner to the equatorial belt of maximum temperature (p. 80), the range and period of movement being about the same.

We are now able to represent the members of the planetary circulation by a diagram. Fig. 6 shows the general positions, and the chief characteristics, with the popular names

The table below gives the mean positions of the equatorial belt and the sub-tropical high-pressure belts in the Pacific and Atlantic

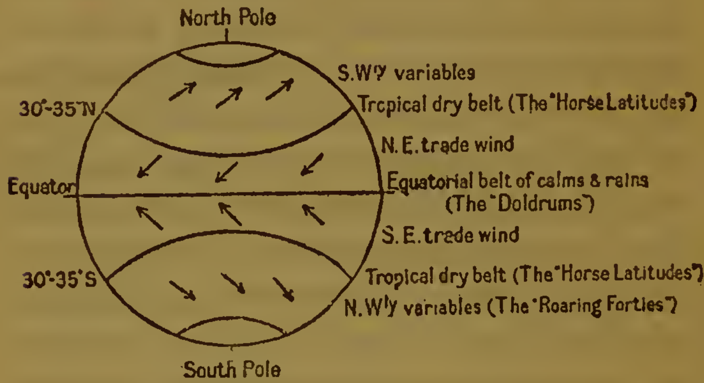


Fig. 6.

oceans (where they are subjected to the least amount of disturbance) at the extreme points of their migrations—

	March.		September.	
	Atlantic.	Pacific.	Atlantic.	Pacific.
N.E. Trade	26°N. - 8°N.	25°N. - 5°N.	35°N. - 11°N.	30°N. - 10°N.
Equatorial Calms	3°N. - 0°.	5°N. - 3°N.	11°N. - 3°N.	10°N. - 7°N.
S.E. Trade	0° - 25°S.	3°N. - 28°S.	3°N. - 25° S.	7°N. - 20°S.

In the equatorial belt the high temperature, the generally abundant supply of vapour, and the strong ascending movement of the air, make the climate one of excessive precipitation. Convectional action attains, in fact, its highest development. Seasonal variations

are almost absent, but diurnal changes are more marked than in any other part of the world. Temperature ranges from intense heat during the day to distinct coolness in the early morning. Along with this we find normally much mist and dampness in the early hours of the day, followed by a period of rapid warming and clearing which culminates in an "afternoon thunderstorm" bringing heavy rain, and is followed by a quick fall of temperature as the sun goes down. The characteristic thunderstorm type of weather is remarkable: it is probably due to the strong convectional action occurring in a region so close to the geographical equator that the deflecting force due to the earth's rotation scarcely comes into play.

The equatorial belt being one of "constant precipitation," *i. e.* there being no dry season within the climatic belt itself, great importance attaches to its migrations. The general positions under the conditions of least disturbance are given in the table on p. 90. Let AB (Fig. 7) represent the most northerly position of the equatorial belt in September.

Then to the north of the line A we have a region of deficient rainfall in the north-east trades; south of B another dry region in the south-east trades, and in the strip AB a wet season with heavy rain daily. As time goes on the belt moves southward, the strip AB gradually passes into the dry conditions of the north-east trades, the south-east trades recede southward and their place is taken by the

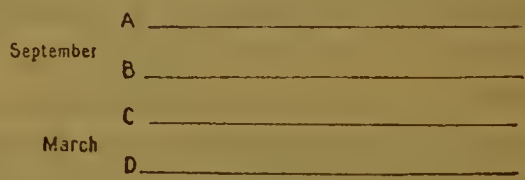


Fig. 7.

rainy equatorial belt. In March the position CD is reached, all points between A and C having experienced a wet season and passed into the north-east trades, while in CD the rainy season is going on. The return northward follows, and at the end of a year the belt is back in its position AB. We observe that the region between B and C has experienced *two* rainy seasons, one during the migration southward and one during that northward, and this, the

double rainy season, may be said to constitute the typical feature of the equatorial climate. The land region where it is most characteristically developed is probably equatorial Africa: for reasons which will be discussed later the normal type is commonly interfered with elsewhere.

Outside the belt of double rains (BC) we have belts AB and CD where there is only one rainy season, and we note that the annual rains continue longest at B and C, and the wet season becomes progressively shorter towards A and D, simply because the equatorial belt passes over B and C in its full breadth, while A and D are only touched by the polar margins. Probably the best example of a region of this kind is to be found in the strip extending across northern central Africa south of a line joining the northern bend of the Niger (say 100 miles north of Timbuktu), and Khartûm: the type of climate is, as will appear later, of rather exceptional importance.

[The student who has any difficulty in understanding the sequence of dry and wet seasons may find it useful to cut a strip of card the

width of AB or CD to represent the equatorial belt in which it rains every day, and to move it northward and southward upon the map within proper latitudes, remembering that all parts covered by the card at any time are experiencing a rainy season, while drought is occurring in the parts left exposed.]

The absence of violent vortex motion in the air in the equatorial belt, notwithstanding the powerful convectional action, may seem remarkable. It is probably to be accounted for by the weakness of the force due to the earth's rotation, which would seem to be an essential factor in the development of the so-called "cyclonic" systems which constitute most storms both within and beyond the tropics. For we find that in those regions and at those seasons where the equatorial belt is farthest from the geographical equator, *i. e.* where the deflecting force due to the earth's rotation gets a chance to make itself felt, tropical hurricanes of the most violent type are generated in considerable numbers, along the polar margin of the belt. These hurricanes usually follow the general westward motion,

travelling along the margin of the belt where they originate until a "weak spot" in the trade-wind zone is reached, when they escape into the region of westerly variables. Thus, referring to the table on p. 90, we find the typhoons of the China seas and the West India hurricanes occurring chiefly in August and September. Hurricanes are rare in the South Pacific and unknown in the South Atlantic, the equatorial belt remaining north of the geographical equator for reasons which are given on p. 119. The northern Indian Ocean may be ruled out of the planetary circulation, but in the southern Indian Ocean we have cyclones of similar origin visiting the regions of the Seychelles, Mauritius and Mozambique, during the months March and April.

The most noticeable feature of the trade-wind belt is the steadiness of the air movement. The winds blow "trade," *i. e.* direct, and derived their name from this characteristic, not from the advantages which they offered to commerce. The contrast between these "trade" winds and the "variables" of the west-wind belts is very marked. The

latter are what are known as "prevailing" winds, the movement is on the whole eastwards, but at any place there may be days and even weeks at a time during which the wind never blows from any point of the west. The trades on the other hand are steady, permanent winds, varying in strength to some often considerable extent, but rarely shifting in direction through more than a few points of the compass and never entirely losing the westward component. Definite proof of the precise cause of this difference is still wanting, but we may recall the fact that whereas because of the earth's rotation the west winds are tending poleward *against* the direction which would naturally result from the temperature gradient, the movement of the trades towards the equator follows that direction (p. 84): the contrast between the disturbed and steady motions is therefore not surprising. Not only is the absence of vortex motions generated within the trades remarkable, but it is characteristic that no systems of the kind are able to invade their domain, except where, for some special reason, the trade winds themselves are unduly

weakened. Hence the restriction of the routes followed by tropical hurricanes (p. 94), and the freedom of the trade-wind belt from trespass by the rotating systems of the west-wind region.

The trade winds, being chiefly fed by the air descending in the high-pressure belts, are usually intensely dry in their higher latitudes, arid conditions extending for long distances from the belt of maximum pressure. The effect of this becomes apparent on land by the prevalence of desert close down to the zone coming within the range of migration of the equatorial belt, as on the southern margin of the Sahara north of the line referred to on p. 93. At sea the same effect is marked by the high salinity of the surface water, due to excessive evaporation. As we approach the equator the air of the trade winds shows signs of having acquired large quantities of aqueous vapour: the great heat of the afternoon sets up feeble local convection currents which, if they do not attain the climax of the "afternoon thunderstorm," are marked by the formation of large quantities of heaped

"cumulus" cloud at their summits, where condensation sets in. Comparatively little outside interference (as from the presence of elevated land) is sufficient to weaken the trades almost to vanishing point, especially where the near proximity of the equatorial belt marks a beginning of distinct ascending movement. Hence we not infrequently find that a part of the trade-wind region becomes as it were merged in the equatorial belt, with a marked rainy season at the time when that belt is nearest. This effect is perhaps most apparent in some parts of Central and South America, where the seasonal variation is described by the saying that "the rain follows the sun."

The characteristic dryness of the belt of maximum pressure has already been mentioned. It will be understood, from what has just been said about the polar margin of the trade-wind region, that no precise boundary can be laid down between the trades and the "horse latitudes." The air descending in this zone is gradually drawn away to the trades, but the mariner's difficulty in "picking up the trades" at their "root"

is sufficient expression of the variableness and uncertainty of the line where definite horizontal motion to the westward sets in. Also, there is no marked change in humidity. This uncertainty is to be accounted for by the fact that the so-called "horse latitudes" are not, strictly speaking, belts of calms, but of light variable winds. The air does not descend uniformly in one mass, but in constantly changing vertical currents, strong at one place, weak at another. Round the centres where the descending movement is for the moment strongest and the surface pressure greatest, the air, as it spreads out over the earth's surface and is deflected because of the earth's rotation, forms vortices or eddies, the wind circulating in the direction of the hands of a watch ("clockwise") in the northern hemisphere and the reverse ("counter-clockwise") in the southern hemisphere. These eddies are known as *anticyclones*, and under favourable conditions they travel along the belt of the horse latitudes from west to east, in close succession. The anticyclones are usually oval in shape, the longest axis being in the direction

of progressive motion, and since the pressure gradients are slight the wind circulation is slow, light winds blowing around large central areas of almost complete calm. The eastward movement of these anticyclones is often fairly rapid. No one system of the kind persists for any great length of time—the tendency is rather to constant dissipation and reconstruction, but the predominance of the type is very marked, systems of the low-pressure type, or *cyclones*, to be described shortly, being rare.

In view of the very gradual change which takes place in the general climatic conditions on the equatorial side of this belt the effect of migration in transferring any part of the earth's surface out of the horse latitudes into the true trade-wind region, or vice versa, is ill defined. The climate of the west-wind belt, on the other hand, shows such a strong contrast, chiefly through the occurrence of fairly abundant rainfall, that the transference becomes very important. Considering for the moment only the northern hemisphere, and referring back to Fig. 7, let the strips AB and CD

represent now the extreme positions of the high-pressure or anticyclonic belt. In September the region north of A lies in the west-wind belt, south of A we have the high-pressure belt and the trade winds. After September the high-pressure belt recedes towards the equator, and in March it has reached the position CD, the region between A and C having passed into the west-wind belt. It is evident that the polar margin of the high-pressure belt, however ill defined it may be, marks the boundary between certain drought and possible rain. The region AC has rain in winter and drought in summer, the dry season being longest, and the wet shortest, in the south, while in the north the transition to wholly west-wind conditions takes place gradually. The sequence in corresponding latitudes of the southern hemisphere will be easily understood.

Since the rainfall occurring within these zones is derived from the west-wind belt it may be more fully considered later in that connexion. The type of climate resulting from these migrations is, however, so much

more completely developed along the Mediterranean Sea and to the east of it than elsewhere that it is well to give it now its usual name of the "Mediterranean type." Similar climates occur in California, on the west coast of South America, at the extreme tip of South Africa, and along the south coast of Australia.

The varying direction of movement in the west-wind belt is due to the constant formation of vortices, either high-pressure anticyclonic areas in which air is descending, or their counterpart, the cyclonic low-pressure areas, where the air circulates counter-clockwise in the northern hemisphere, clockwise in the southern. In the cyclone air ascends, and there is consequently much condensation when gradients are steep, accompanied by strong winds. Shallow cyclones, in which the barometric gradient is slight, are of frequent occurrence, and in these the circulation of air may become very feeble and uncertain in direction. Within such shallow "primaries" smaller "secondary" cyclones are often generated, and these are commonly accompanied by heavy local rainfall with electrical disturbance

—the typical "thunderstorm" rainfall of the temperate zones.

Great variations occur in the size, number, and intensity, and in the direction and rate of motion of both cyclones and anticyclones. The one invariable feature seems to be their large diameter and small vertical height: the systems are, in fact, thin rotating slabs of a circular or oval form. A cyclone of average size, for example, may be three or four hundred miles across, and some five to seven miles in height. Both primaries and secondaries are to be clearly distinguished from local vortices of a quite different type, also usually generated within weak primaries in consequence of special local conditions. These are known as "tornadoes" on land and "waterspouts" at sea: their diameter—ranging up to a few hundred yards—is much less than their vertical height. The rotational movements in these disturbances are extremely rapid and the winds blow with destructive violence.

Where the surface conditions are uniform (and greater uniformity is attained in the middle

latitudes in the southern hemisphere than in any other part of the world) the tendency seems to be for cyclones to preponderate and to form a ring of maximum depression in about latitude 60°, around which the systems pursue each other eastwards with great speed. On the equatorial side of this ring we have the ring of anticyclones whose axis forms the high-pressure belt, and on the other a polar cap of high pressure.

The mechanism of these cyclones and anticyclones is still far from being fully understood. Observation shows that each cyclone has an anticyclone, and each anticyclone a cyclone, not directly above it, but somewhat to one side (p. 70); but the originating cause, which is still unknown, is certainly not convection. It is well to recall at this point the extreme complexity of the conditions. We have, as a result of the temperature gradient, a tendency for (1) an upper current of warm air to move towards the poles, and (2) an under current of cold air to move towards the equator. The former, which, in the end, must supply the latter (as

a return current) is (3) driven back into lower latitudes by the forces due to the earth's rotation. We can well imagine that where all these forces are vigorously at work one current will not flow peacefully over the other, but that constant breaking up and down into streams or "streaks" will occur at various levels, so that streams may flow in opposite directions side by side, setting up vortical motion along the face between. Recent investigations go to show that the cyclones and anticyclones are "eddies" in the larger streams, and that the winds at the earth's surface are not in the first instance merely connecting currents whereby the air descending in an anticyclone is fed into the up current of the nearest cyclone. This generalization (due chiefly to Shaw and Lempfert) is perhaps the most important contribution which has been made to meteorology in recent years. Its significance is so profound, and the difficulty of fitting its consequences into the existing theories of the planetary circulation so great, that we make this attempt to summarize the results so far obtained with

much hesitation. Perhaps it would have been better to say "nothing is known with certainty about what the circulation would be if there were no land or no sea." But an account of weather and climate would then have been reduced to the monotony of mere description; it would have been extremely difficult to make it intelligible, and impossible to give any clear indication of how the slow growth of knowledge in meteorology has been brought about. Simple as are the elementary physical properties of air and water vapour, the fact that they include compressibility makes a general investigation of their behaviour on a rotating sphere, even with the simplest assumptions as to temperature, quite beyond the powers of known mathematical methods.

CHAPTER V

THE INFLUENCE OF LAND AND SEA UPON THE ATMOSPHERE

The final restriction which we have hitherto retained in the interest of simplicity is the uniform surface of the earth. In removing this we are at once confronted with the primary division of the surface into land and water, or, for our elementary purposes, land and sea, and the secondary and less important division of the frozen surface of ice or snow.

The temperature conditions existing upon land and sea have already been compared. With the same amount of insolation, a land surface heats and cools through a much wider range of temperature than a sea surface, and this is more the case with a dry sand or limestone surface than with a moist impermeable surface like clay. Thus in varying degrees we have under certain

circumstances (see p. 32) wide differences of temperature between a land surface and a sea surface in its neighbourhood. These variations of temperature are communicated, in accordance with the principles already explained, to the air resting upon the respective surfaces and ultimately, by convection or otherwise, to considerable heights in the atmosphere above. Another point is that over the sea the supply of water vapour is unlimited, and consequently if ascending currents are set up from any cause condensation soon follows, strengthening the so-called cyclonic conditions by increasing the barometric gradient and therefore the force of the rotating winds. Deep primary cyclones are characteristic of oceanic areas.

On the other hand, even the intense heating of continental areas, with the favourable convectional conditions which result, is less frequently accompanied by the occurrence of deep cyclonic storms: the tendency is rather towards the formation of shallow cyclones in which secondaries, of one type or another, are apt to develop. The rainfall in such regions

is therefore chiefly of the "thunderstorm" type, and occurs for the most part in summer. During the cold season these large land areas are covered by air which increases in density as it cools, and anticyclonic conditions prevail. There is great dryness, and hence strong radiation, which lowers the temperature still further until outside the tropics such extremes as those of north-eastern Asia are experienced ($-80°$ to $-90°$ F.), far transcending the minima of the highest latitudes. Under these conditions the atmosphere remains almost inert—it has no tendency to move as a whole, but the fringes of the cold area expand and contract like the rim of a jelly-fish. The barometric gradients are again very slight, and there is little wind.

In the trade-wind belt, where even at some distance from the geographical equator the seasonal variations, and therefore the differences, of temperature are comparatively small, the effect of the general westward movement is in itself not very great. As we approach the axis of the

high-pressure belt, however, the higher temperature of the land in summer eauses a reduetion of pressure, a break in the line of antieyelones, whieh interrupts the normal trade-wind movement and allows the passage of tropical hurrieanes into the west-wind region (p. 94). Near the equatorial belt itself the effeet is, for reasons now obvious, not so apparent. At and beyond the latitudes of the high-pressure belts we eome to the zone in whieh (p. 33) the seasonal differenees of temperature between land and sea attain their maximum. Near the high-pressure axis itself, where the body of air is not moving rapidly either east or west, the differenee produees little pereeptible effeet, as appears, for example, in the region of the eentral and northern Sahara, where, notwithstanding the intense heat of the summer months and the proximity of the Atlantic, ealm reigns on three days out of four, and almost the only disturbanee is the local dust storm. No definite homogeneous eirculation is established ; on the contrary, even the antieyelonie pulsations, so marked in the southern hemisphere (p. 99),

can scarcely be recognized along the whole long line of land.

The general easterly movement in the west-wind belt makes itself very clearly felt. The primary rain-bearing cyclones, generated in large numbers over the Atlantic and Pacific oceans in winter, travel eastward towards the land masses, but are only able to invade them where the land is of so small extent that the protective high-pressure areas are not established. Where these cyclones meet a continental high-pressure area they are in general unable to penetrate, and are usually deflected polewards, skirting round the western margin of the stationary system. Thus in Africa and Australia the extreme southern portions have the cyclonic winter rain characteristic of the Mediterranean type of climate (p. 102). South America, jutting farther southwards, has a strip of Mediterranean climate and an area with "rain at all seasons" beyond. In North America some of the winter cyclones from the Pacific are deflected northwards, entrance being to a certain extent barred by the high land

and the continental high-pressure arca (p. 109). Western Europe, thanks to its broken coast-line, with inlets like the Baltic, and still more the Mediterranean, not only gives the winter cyclones access far to the eastward, but supplies them with abundant fuel in the shape of water vapour. In the case of the Mediterranean the eastward line is prolonged by the Black Sea and the Caspian, so that the winter rainfall extends into Asia Minor and even into western Persia. Farther north the winter cyclone rainfall ceases much more to the westward, but it covers the British Isles, northern France, and most of western Germany.

In summer the land conditions are mildly cyclonic. The oceanic cyclones can, and do, make their way into the "hearts" of the continents, alive or dead, but in the northern hemisphere at least they are feeble and few in number, and on land they are soon starved through lack of water vapour. They are, of course, excluded from the Meditcrranean belts at this season. We thus have, on the western sides of the great land masses of

the northern hemisphere, and across South America (beyond the latitudes of the Mediterranean belt) and southern New Zealand, rain at all seasons from ocean cyclones, but chiefly in winter when these are strongest and most numerous; and in the hearts of the continents rain in the late spring and early summer, chiefly from the local secondaries generated within feeble primaries.

On the western sides of the oceans the climatic conditions in the west-wind belt are largely those transferred or extended from the land regions, where these are of sufficient area. The extreme conditions of north-eastern Asia and eastern North America both in winter and summer are appreciable far out into the Pacific and Atlantic oceans. In the southern hemisphere, where the land scarcely extends into the west-wind belt except in the case of the narrow end of South America, the chief effect noticed is a comparatively slight deflection or twist given to the normal eastward track of the cyclones during the winter months.

Much has been written during recent years

about the modifying influence of ocean currents upon climate generally, and in many cases the loose impression conveyed is that currents act in somewhat the same manner as the heating apparatus of a greenhouse. It should be understood that no body of water can by its temperature affect any air except that resting directly upon it, and neighbouring land can only be influenced when that air is transferred to it from the sea. The Gulf Stream and the Labrador current both flow at a short distance from the east coast of North America, but their influence for good or evil upon the climate of that continent is extremely small, because the general drift of the atmosphere is from the land. The mixed waters of these currents, drifted across the Atlantic, almost along a parallel of latitude for a great part of the way, show no considerable excess of temperature, nevertheless the west coast of Europe has an equable climate because the prevailing winds come from the sea. In the lower latitudes, as far north as the British Isles, very little effect would be produced by the removal of the

North American continent and the consequent stoppage of the two great stream currents. What has been said of the Atlantic holds equally for the Pacific; the Kuro-Siwo replacing the Gulf Stream; Asia, North America; and the coasts of Oregon, Washington, British Columbia and Alaska, the western part of Europe. There is in the Pacific no effective counterpart to the Labrador current.

The part played by oceanic currents becomes, however, important in relation to the fact that, other things being equal, a cold surface, by lowering air temperature, tends to increase pressure, and a warm surface, by raising air temperature, to diminish pressure. If temperature is below the normal in an anticyclonic area, the anticyclonic conditions will be strengthened: if it is above the normal, they will be weakened. Where the conditions are cyclonic, unusually low temperature weakens them, high temperature reinforces them. In the latitudes of the high-pressure belts the great oceans have currents moving poleward on their western sides, and towards the equator on their eastern

sides; that is to say, in the west the water is moving from a warmer region to a colder, and on the east from a colder region to a warmer. As the temperature changes slowly, the surface on the west side is therefore relatively warm, and on the east relatively cold. Hence the average intensity of the eastward-moving anticyclones reaches a maximum just to the west of the continents, as appears from the charts of mean pressure. (Plates 3 and 4.)

Another aspect of this action presents itself in the special case of the North Atlantic. The North Atlantic is connected with the Arctic Ocean by three main channels, one between Europe and Iceland, another between Iceland and Greenland, and a third between Greenland and America. By a process which need not be discussed here the strong cyclonic winds in the Atlantic send vast quantities of relatively warm water northwards to the ice-encumbered regions of the Arctic, with the result that much of the ice is melted. The ice-cold water, light notwithstanding its low temperature because it is fresh,

keeps to the surface and makes its way down into the Atlantic somewhat in the manner suggested on p. 105 for warm and cold currents of air, and eventually mixes and spreads itself over wide areas. It is evident that we have here a sort of compensating cycle. Warm surface water in the Atlantic means low pressure, and therefore strong cyclonic conditions; strong cyclonic conditions mean much warm water sent northward; much warm water sent northward means much ice melted, and much cold water sent southward. But much cold water sent southward means lower surface temperature in the Atlantic, and therefore weaker cyclonic conditions, therefore less warm water sent northward; and eventually less ice melted, less cold water, warmer surface temperature, stronger cyclonic conditions, and so on. A recurrent system of this sort will obviously work irregularly, with a wide range of variations, but it must be accepted as one of the factors which goes to modify the direction and strength of the great air currents in the northern hemisphere.

Another illustration of the profound effects

of the distribution of land and sea areas upon the planetary circulation may be obtained from a comparison of the two hemispheres. In the southern hemisphere, especially in the higher middle latitudes (40° to 60° S.), the surface of the earth is very largely ocean. The atmospheric circulation occurring agrees very closely with the standard or planetary system. In the horse latitudes the anticyclonic pulsations are, as Dr. Lockyer has recently shown, distinctly traceable, and beyond them the west-wind low-pressure belt is traversed by a constant succession of deep primary cyclones, the "brave west winds" which blow in the "roaring forties." Pressure is everywhere lower in summer than in winter. But in the northern hemisphere, where the proportion of land to sea is great, the normal circulation is distorted to such an extent that it is often scarcely recognizable. One of the most remarkable features is the anomaly in the seasonal distribution of pressure over the North Atlantic and North Pacific. The surface temperature of those oceans is, of course,

higher in summer than in winter, nevertheless in all latitudes beyond the tropics pressure is also higher in summer than in winter, contrary to all experience elsewhere. The cause is pretty certainly to be looked for in the fact that the high-pressure systems over the continental areas, with their anticyclonic circulation, must be compensated by ascending (*i. e.* cyclonic) movement in some region where temperature is higher, and this is found over the oceans, hence the winter maximum of strong primary cyclones. In summer the weak cyclonic conditions over the vast land areas must be similarly compensated by higher pressure somewhere where temperature is lower, and this is again found in the oceans. Thus the contrast between oceanic and continental climates is in a sense intensified in the northern hemisphere.

One other effect of the great activity of the planetary circulation in the southern hemisphere is that in those parts where it is least disturbed, as over the oceans and Africa, the axis of the equatorial belt or the meteorological equator, as it is convenient to call it,

lies north of the geographical equator, the average displacement amounting to as much as four or five degrees of latitude. The positions are shown in the table given on p. 90.

Besides the difference in the thermal properties of land and sea surfaces, there is the almost equally important difference of configuration. In the case of water the general surface is necessarily horizontal and at the same level in all its parts, but over the land there is no such restriction. A slope upward from the coast may extend over great areas, and large horizontal surfaces may occur within a wide range of elevation.

Consider first a horizontal surface or plain near sea-level. When this becomes greatly heated by the sun's rays a thin layer of air resting on the surface is quickly raised to a high temperature; it becomes lighter and tends to rise. Immediately above it is a much denser stratum, keeping it down, as it were, and the two layers must change places. It is easy to see that a breaking-up of the two layers must take place, small parts

of the warm layer rising up through the cold, and small parts of the cold sinking down through the warm. The result will be frequent local disturbances of either the secondary or tornado type (p. 102), but until the warming of the atmosphere has gone on long enough to raise the air temperature over the plain as a whole to a considerable elevation, there will be no great upward transference of air and therefore no serious demand for a supply by indraught from surrounding regions. The conditions will be those observed on a dusty road on a hot summer day: spiral columns of dust rise here and there, travel along for a short distance, and then subside, but there is no hint of steady ascending movement over the whole road, or of air flowing in from the road-sides to replace that which has gone up. We refer again to the Sahara with its spells of calm and occasional dust storms.

When the surface of the plain is cooled, the air next it, falling in temperature, simply settles down. There is nothing to move it, and the colder it gets the more closely it

adheres, until again the cooling may extend to considerable elevations.

What holds good of a plain near sea-level holds equally of a plain or plateau at any elevation. The mean temperature is, of course, affected by the normal fall of the temperature of the whole atmosphere with increase of height (p 77), but insolation is not affected,

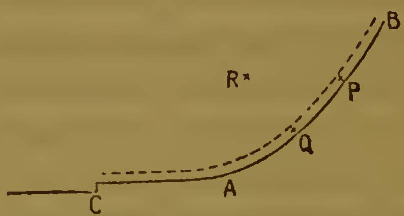


Fig. 8.

neither is outward radiation, except that both may be more intense on account of the greater dryness : hence the conditions remain the same.

If we take the case of a sloping surface of land the conditions are very different. Let AB, Fig. 8, represent the edge of a slope near the sea, the coast being at C, and AC representing a coastal plain. Let the space included between AB and the dotted line

represent the edge of a layer of air next the land surface, P and Q any points in that layer. If the surface AB is greatly heated the air at P will become warmer and therefore lighter than that in the open atmosphere at a point in the same horizontal plane, say R, and it will tend to rise. Similarly, the air at Q will become warmer than that at S, and so on. But as P rises, Q, which also wants to rise, naturally takes the line of least resistance and occupies the place vacated by P. A continuous steady current ascending the slope is therefore set up and the place of the ascending air must be supplied by air from the nearest cool region; thus there is an indraught across CA and up the slope from the sea.

Similarly, if the surface AB is cooled by radiation the stratum of air resting on it is cooled and becomes heavier, Q tends to roll down the hill, so does P; P occupies the place vacated by Q, and there is a current flowing downwards and out across the plain to the sea.

There is thus in both cases opportunity

for active circulation, and we observe that in the case of the indraught the air drawn in from the sea is probably well supplied with aqueous vapour; condensation will soon set in as the ascending air expands (p. 58). The outflowing air, descending, is being warmed and dried. The time of general indraught is therefore usually (but not always) a time of rain, that of outflow a time of drought. Ferrel (*Popular Treatise on the Winds*) not unfairly compares the case of the level plain to that of an open camp fire or a fire without a chimney, and that of the slope to a stove with an upright flue in which heating induces a fierce draught.

The occasions on which well-marked differences of temperature arise are of two kinds: those due to rapid diurnal heating and cooling, and those due to rapid seasonal heating and cooling. The former are characteristic of low latitudes, and the latter of middle latitudes (p. 32); and in those regions, given favourable conditions of slope, we have in the one case the diurnal *land and sea breezes*, in the other the seasonal *monsoons*.

Taking the land surface of the globe as a whole, monsoonal action plays by far the most important part in modifying the planetary circulation. In certain regions it develops such strength as practically to destroy the whole planetary system, in some it reinforces it, and in many, one might say most, parts its influence is to be traced. We will deal in a later chapter with the regional results.

Another case which must be noticed is that of the effect of a ridge or range of elevated land upon a current of air of which it is not the cause. Nobody supposes that the Pennine axis is the cause of the winds which prevail in northern England, yet the Pennines exercise great influence upon the climate of that region. Take first the case where the range runs at right angles to the wind, and suppose the air to be fairly supplied with water vapour. Then the air must obviously rise as it meets the ridge, and as it rises it expands and cools, and condensation takes place. Thus the rainfall is increased, and the increase is greater the steeper the slope which the air

is forced to ascend. The air usually continues to ascend, as by its own momentum, after the summit of the ridge is passed, and the actual heaviest rainfall occurs not on the weather side but on the lee side just beyond, as at Seathwaite in Cumberland. If the wind meets the ridge not at right angles but obliquely, the effect will be the same as if the ridge were diminished in steepness, the rate of ascent is slower and the precipitation is spread over a larger area. We observe that in a cyclone, and indeed in any atmospheric vortex, the vertical movement is very slow compared to the horizontal, so that the normal rainfall (as *e. g.* the rainfall at sea) is increased in enormous proportion by the sudden deflection of the horizontal component upwards; hence, for example, the great difference of rainfall between the coast and the interior in the Lake District of England, the west Highlands of Scotland or the Malabar coast of India. It is well to appreciate the full significance of this mechanism in producing and increasing rainfall, and to keep clear of the mistaken notions which find

their extreme expression in forms suggesting that clouds "condense" and become bags full of water, which burst on coming in contact with mountains, hot or cold.

On the lee side of the ridge after the air has reached its highest point and the narrow "rain-shadow" of greatest fall is passed, the current begins a downward movement. Sinking to a region of greater pressure the air is compressed, warmed, and dried, and radiation at the earth's surface greatly increased. In a wind coming from the sea and penetrating inland the effect is practically to discharge the oceanic element prematurely on the weather side and anticipate the "continental" type of climate on the lee side. Examples of this are easily seen in the British Isles and western Europe generally. Where the land is low to the coast the "oceanic" type of climate, with its equable temperature, and moderate rainfall distributed all the year round but mostly in winter, penetrates far inland (as in the southern midlands of England, the lowland plain of Scotland, and north-western France).

But where a high ridge faces the sea, as in Scandinavia and the centre of England, the rainfall is greatly increased on the western side (Wales, Norway), while on the eastern side (the central midlands of England, Sweden) it is less than in the former case at the same distance from the weather coast, and it tends to the "thunderstorm" type with summer maximum; also the range of temperature increases. The same thing occurs markedly in the Deccan east of the Western Ghâts, and again on a large scale on the Pacific coast of North America.

This dry descending wind often forms a special feature of local climate, more particularly where air is drawn down by low-pressure areas passing over the sea or low-lying ground, with a mountainous hinterland near by. The air descending the northern valleys of the Alps appears as a warm dry wind—the "Föhn"—which often causes violent flooding by the amount of snow melted through its warmth. The "Chinook" coming down from the Rockies to the Canadian plain, notably in Alberta, is a similar wind. Where the

descent is made to a region much warmer than that of origin a wind of this type, although warmed on its way, may still remain relatively cold. In this latter group we may include the winds drawn down the southern flanks of the Alps to feed the cyclones in the Mediterranean —the "Mistral" in the valley of the Rhone and the coast region between Genoa and the mouth of the Ebro, and the "Bora" on the coast of the Adriatic. Similar winds occur in the Caucasus, and many of the innumerable varieties of local winds observed all over the world are probably of this type.

A word must be said with regard to the position of isolated high peaks, as distinct from plateaux, extensive slopes, or continuous ridges. In their case the surface of land exposed is in general of too small extent to produce any but quite local monsoonal action, and they are mostly ineffective in causing an air current to rise, the horizontal movement being merely deflected so that the wind blows round the mountain. The conditions at the summit of a peak approximate more or less completely to those in the open atmosphere

at the same elevation, but the amount of disturbance due to the mountain mass itself is extremely difficult to estimate in any particular case. In other words, observations taken at a station on a mountain summit may be very much like those taken at the same level from a balloon or kite, but they are affected by the mountain in a manner and degree which is different for each mountain. It is to this fact that we must attribute the great uncertainty which arises in drawing any general conclusions from comparisons of observations made at pairs of stations at the bases and summits of mountains, especially when the peak does not stand alone, but is in a mountainous region.

The general characteristics of a permanent ice or snow surface have already been indicated (p. 31). No lower limit of temperature can be assigned, because temperature being always low the amount of vapour present in the atmosphere is small, and radiation may take place freely from the surface till it becomes extremely cold. A superior limit is imposed by melting, so that the air tempera-

ture can never rise above 32° F. in consequence of contact with the surface alone. Higher temperatures must be due either to direct absorption of heat by the atmosphere or to winds transferring warm air from a more genial region. The boundary between those regions in which, on the average, the amount of ice and snow formed is greater than the amount melted and those in which it is less is called the *snow-line.* The elevation of the snow-line undergoes great local variations according to the exposure of the surface (as on the north and south slopes of mountains), but it is, generally, highest above the equator, where its mean height is about 16,000 feet, and it declines with increase of latitude till it reaches sea-level beyond the polar circles. Round each pole an "ice-cap" is formed, and the distinction between land and sea surface disappears except as regards configuration. The northern ice-cap is a frozen sea-level plain covering the Arctic Ocean, except over Greenland and the north of North America, and it affords many points of contrast to that in the south, which rests

on the unbroken land mass of the Antarctic continent at an average elevation of some thousands of feet above sea-level. (See volume on *Polar Exploration.*)

Our knowledge of the meteorology of the polar regions, both north and south, has been greatly increased during recent years by the expeditions which have penetrated into the highest latitudes, and, still better, have maintained observing stations taking continuous records simultaneously at fixed points for months at a time. But it is still dangerous to venture upon conclusions as to what the prevailing conditions really are, or to attempt to "place" the regions finally in a scheme of planetary circulation. The whole belt surrounding the Arctic cap is, as we have seen, greatly modified by the distribution of land and sea, and the high average elevation of the Antarctic continent introduces an element of great difficulty in understanding its precise relation to the low-pressure cyclonic zone over the continuous ring of ocean which surrounds it.

The general position would seem to be that

over each cap there is a permanent area of high atmospheric pressure, very much like the winter high-pressure areas in the temperate zones of the great continents, and that from this single anticyclone air flows at the surface into the cyclones of the encircling belts of low pressure. This would account for the alternation of warm north-easterly and cold south-easterly winds observed round the margin of the Antarctic continent, and the cold southerly winds encountered by Sir Ernest Shackleton in his journey towards the South Pole. Even in the northern hemisphere these outflowing winds are an important feature, inasmuch as occasional lapses of the west wind circulation, sometimes persistent and always puzzling, allow them to effect a direct junction with the trade-wind currents at the surface, giving long stretches of cold northerly winds extending over many degrees of latitude.

CHAPTER VI

CLIMATIC REGIONS: THE MONSOON REGION

We have attempted, in the preceding chapters, to give some outline of the chief elements which help in determining the physical state of the atmosphere at different parts of the earth's surface, and the varied changes which occur in that state from time to time. The average state at any place, with regard especially to temperature, the direction and strength of the winds produced by differences of pressure, and the amount of moisture held as vapour or precipitated, may now be defined as the *climate*, and the state from time to time, within the limits of deviation from the average, as the *weather* at that place. Speaking generally, variations of weather are more frequent and irregular in high latitudes than in low.

From what we have learned, we are now

prepared to find that the climate (which for this purpose includes the weather) at many different places offers certain features of similarity, and that taking advantage of these features we can arrange places in groups or districts, each place within the district having a climate of the same general type with only minor differences. We are in this way able to break up the surface of the earth into *climatic regions*. The task is, as will be understood, no easy one. The primary factor is the great divisions of the planetary circulation, and the secondary factor the modifications which the distribution of land and sea and the configuration or relief of the land produce in each of these main divisions. In this way we might get, first, an intertropical belt which would include as subdivisions the Doldrums, the zones of the trade winds and the horse latitudes, the two extratropical west-wind belts, and the circumpolar caps. Each of these divisions and subdivisions would again be broken up, in many cases quite arbitrarily, into smaller districts according to the manner and extent of action of the land and sea

influence. This subdivision could obviously be carried out to any degree of refinement required for special purposes, and at any desired point other meteorological or even non-meteorological elements might be introduced as a basis of subdivision; such as soil-constituents, distribution of certain plants or groups of plants, and so on.

We propose in what follows to indicate the positions, limits and chief characteristics of the larger climatic regions, founding a classification on the considerations just stated except in one case. There is one region, roughly that of south-eastern and eastern Asia and north-eastern Australia, in which the land and sea influence is so strong as to override the planetary circulation altogether, and replace it by what is practically a monsoon climate pure and simple. Just as in describing the planetary circulation we have referred constantly to the parts of the open oceans in which that circulation attains its highest development, so it is convenient to take south-eastern Asia as the standard type of monsoon climate in trying to estimate the

relative importance of the two factors elsewhere.

The fact that in discussing the atmosphere from the physical point of view we have made liberal use of illustrations taken from different climatic regions, makes a certain amount of repetition in examining it from a geographical standpoint unavoidable. The amount of such repetition need not, however, exceed what is convenient and even desirable in a book of this kind; it will not approach the limit at which excuses for it have to be sought for.

We have, then—

1. The equatorial belt.
2. The trade-wind belts, north and south.
3. The high-pressure belts, north and south.
4. The west-wind belts, north and south.
5. The circumpolar caps.
6. The monsoon region of south-eastern and eastern Asia.

Here the regions numbered 1 to 5 are simply the divisions of the planetary circulation. The principal characteristics of climate in

those regions in the undisturbed state, as at sea, have already been sufficiently described, and it therefore only remains to trace the effect of the land influence. This being the case, it is well to take the extreme manifestation of land influence first, as it appears in the monsoon region.

In Central Asia we have not merely the greatest mountain systems of the world, stretching from the region of the Pamirs eastwards and northwards to the extreme verge of the continent, but between these mountain systems we have an immense plateau, rising to an average height of sixteen to eighteen thousand feet above the sea. No other elevated region of anything like the same extent occurs in any part of the world. East and south-east of it lie the vast areas of India, Farther India, China and Korea, which for our purpose may be regarded as plains sloping, sometimes steeply, sometimes gently, down to the coast. South-east the land surface is continued by peninsulas and by the largest group of big islands in the world, many of them mountainous, and beyond is the continent of Aus-

tralia, with an irregular raised axis extending farther southwards near its eastern coast. To the east and north-east lie the islands of Japan.

A glance at the map will show that much of this area which lies within the mainland of Asia is included in the belt of the north-east trades, which would represent the normal planetary conditions. In the north-eastern part the mountain system forming the landward boundary is less high and continuous than in the centre and west, hence the separation from the west-wind belt is not so complete as in the centre and west.

In winter all this land surface becomes extremely cold, and pressure is high over the land; the maximum pressure, due partly to the high-pressure belt and partly to the focus of intense cold in north-eastern Siberia, has its centre in a position between the two, in about latitude 45° N. The monsoon at this season blows, therefore, from north and north-east, and in the greater part of India, Farther India and Southern China, simply strengthens the normal trade wind. We have, therefore, a

close approach to the normal planetary conditions, and this season is the best starting-point for an examination of the climatic *régime.*

As the movement of the air has on the whole an outward or seaward tendency and is descending, the season is rainless over a great part of the area; it is essentially the dry season, except in special cases, such as occur where the outline of the coast makes a northerly or north-easterly wind a wind blowing from the sea. A remarkable feature is the extremely low temperature occurring in China, where the air crosses cold plains of vast extent and is therefore little warmed by compression through downward motion. Snow falls and lies nearer the equator in China than in any other part of the world.

During this period the part of the region south of the equator has its hot season. The district which best satisfies monsoonal conditions by a fairly continuous mass of high land sloping to the sea is in Queensland, along the eastern part of the north coast and the northern part of the east coast of Australia. Here the normal planetary wind is the south-

east trade, but in the hot season the monsoonal action draws in the south-east trade with increased force in the south (making it an easterly rain-bearing wind), while in the north the equatorial belt is, so to speak, obliterated, and a strong monsoon is drawn from the north-west—the Malay Archipelago and New Guinea—distributing heavy summer rain over an extensive area. Observe that as we work westwards along the north coast of Australia, this monsoon becomes less and less important and the rainfall diminishes almost to nothing as we reach the low-lying level ground, notwithstanding the intense heat of the interior.

Over India this represents the so-called "cold weather" season. Temperature averages 60° F. to 70° F. in the Indo-Gangetic plain, but increases quickly to the southward. The prevailing winds are north-easterly, usually light in force, and rain (where it occurs) is distributed irregularly.

As the sun moves northwards after the solstice the Asiatic area becomes warmed up, at first quickly, then more gradually as time

goes on. Pressure gives way and the dry monsoon slowly weakens, working round by east southward. Where the normal trade-wind is definitely seaward the heating process goes on for a long time before actual reversal takes place, and there is a period of great drought, during which the atmosphere often attains an extremely high temperature. In India this "hot weather" usually begins in February and continues till about June. The intense heat and aridity at the end of the hot weather is probably unequalled in any region which receives appreciable rainfall at all, and the effect upon a country in which at other seasons luxuriant vegetation flourishes may be imagined.

Eventually the change comes, and, especially where it involves a reversal of the trade winds, as in India, it usually takes place, perhaps after a few "unsuccessful attempts," with suddenness, and accompanied by violent cyclonic disturbances. The "normal" rainfall (*e. g.* that at sea) is very abundant. Breaks occur in the rains from time to time, but the whole season, which continues until September

or October, is continuously moist and steamy. The general direction of this monsoon current is towards the main mass of elevated land, centring around the Himalayas and their extensions eastward, with a distinct deflection to the right in accordance with Ferrel's Law. Thus the south-west monsoon of India and the surrounding seas becomes southerly, south-easterly and easterly as we proceed through Farther India to China, Japan and Korea.

It is difficult for any one unfamiliar with those regions to form any adequate conception of the paramount influence exerted by the summer monsoon over an enormous area. The inflowing air is drawn from far out at sea, and in the Indian Ocean the action is supported and extended westwards by the heated high-lands of Abyssinia. The strength of the winds is such that in many parts of the area coastal navigation is brought to a standstill. Practically only large vessels keep the sea, and a voyage from Bombay to Aden in the height of the monsoon is a disagreeable experience, even in a mail steamer.

The tendency for surface currents of air

to go round rather than over obstacles (p. 129) is well illustrated by the manner in which the monsoon winds split into branches and change their direction on reaching the land, following even quite minor features of the configuration, so that in many cases deflection occurs until the current is running almost parallel to the margin of the elevated land to which originally it owes its existence. This is nowhere better seen than in India, where the monsoon, approaching the land from the south-west, divides into two main branches, one meeting the western coast almost at right angles, and surmounting the Western Ghâts, and a second passing up the Bay of Bengal, at the head of which, meeting the main barrier, it is in part deflected westward up the valley of the Ganges. Between the northern margin of the first branch and the western extremity of the second there is a sort of "dead" area scarcely affected by either, the region of the Thar desert. It is well for the student to notice this special case of a monsoon current blowing along the side of the main raised mass which causes the monsoon, in such a direction that

it is deflected to the left of its normal course and not to the right. Such cases, as in the Ganges valley, are wholly due to the configuration of the land and its relation to the adjacent sea-areas; they are of great interest in some other parts of the world, where they are complicated by other factors, as in the southern United States.

The distribution of monsoon rainfall depends, first, upon the direction and strength of the monsoon currents and, second, upon the local features of surface configuration. In India, for example, the strength of the monsoon varies greatly from year to year, and a weak monsoon is usually late. Great importance is naturally attached to accurate forecasting of the monsoon, and in India this is now done with success. The variations seem to be chiefly due to causes which are operative a considerable time before the monsoon sets in, and probably act in part by delaying the warming-up of the mountain regions and high plateaux; thus an exceptional amount of snow upon the mountains during the cold weather season is commonly regarded as a

prognostic of a weak or late monsoon to follow. The protracted hot-weather period of drought makes it clear that the heating of the low-lying or plain portions of the area is insufficient by itself to produce the monsoon, and that it is only after the slopes of the central mass have been warmed to some critical temperature that the sudden indraught represented by the "bursting" of the monsoon takes place.

Other things being equal, the amount of rainfall will depend upon the angle between the monsoon current and the local trend of the coast-line. On the west coast of India, where the angle is approximately a right angle, a large amount of rain falls, but on the Coromandel coast, where the south-west monsoon in its strength blows nearly parallel to the shore, it brings hardly any rain, and the wet season is delayed until the time when, in the gradual return to the north-east monsoon, the wind blows for a time from south-east and east, and therefore landward.

With regard to the second factor, the local configuration, the conditions are those of a wind passing over an irregular surface,

that surface not being primarily concerned in causing the wind (p. 125). Where the monsoon current is forced to ascend a steep slope condensation takes place with great rapidity and the rainfall is enormous. The region of the Khasia Hills in Assam, and the Western Ghâts, for example, rcceive the heaviest falls recorded in any part of the world, such stations as Chirra Punji and Mahableshwar being especially notorious with regard both to the amounts falling in short periods and thc annual totals. The supply of moisture is so great that, notwithstanding thc heavy run-off due to the generally steep slope, and the long, hot, dry season, these are regions of luxuriant forcst vegetation. It may be pointed out here that the growth of permanent vegetation, which is very effective in forming and retaining a moisture-holding soil, probably dates in rcgions of this type from a long-past geological epoch, when the distribution of the rainfall was more uniform than it is now. Where, as in many parts of the world, deforestation has taken place in a region having extreme dry and wet seasons, re-planting is almost

impossible, for the exposed soil is dried and loosened during the dry season and washed away by the torrential rains which follow.

On the lee sides of the main slopes the rainfall is, of course, much diminished. If the downward slope is at all rapid an arid region without any useful amount of rainfall succeeds almost immediately after the main ridge is passed. Where, as in the Deccan, the general leeward slope is gradual, forming a plateau with a diversified surface sloping gently downwards, light to moderate rainfall is distributed fairly evenly. But this rainfall is, for obvious reasons, very sensitive to variations in the strength of the monsoon current, and hence over large parts of a region of exceptionally fertile soil we find wide fluctuations in productiveness from year to year, a strong monsoon meaning plenty, and a weak monsoon famine. Peninsular India is of peculiar interest in respect that parts of it represent one type of those regions which are subject to excessive variations distributed quite irregularly and often over long periods. In such regions years of adequate rainfall and abun-

dant yield may follow in succession for decades at a time, during which a considerable population settles and opens up the country; then follow a few years of drought, and with the high temperature, aridity; and unless irrigation or storage works are practicable and are executed in time, the land is deserted. One can suppose that an experiment in colonization tried once in a region of this kind (perhaps because of political pressure from outside), successful for a time but in the end proved definitely a failure, is not likely to be soon repeated; and here may lie the reason why the conclusions about the gradual desiccation of some parts of the world, which have been based on the existence of deserted habitations, have never received any support from the testimony of the rain-gauge. Other cases of great variability of rainfall will be considered later on.

Another feature of interest which arises in connexion with parts of peninsular India is the association of high summer temperature with moderate rainfall. We are already familiar, in the Mediterranean type of climate,

with hot, dry summers. In monsoon regions, where the surface is fairly level and low-lying, or slopes gently up from the sea, or where the rain-bearing current ascends a long valley, as in many parts of China, the rainfall, although evenly distributed, is heavy. But the excessive fall on a steep weather slope reduces that on a gentle lee slope to moderate limits, and we have a somewhat special type of climate—one in which there is *a long hot season with moderate rainfall distributed over a considerable period.* The regions where a climate of this sort occurs are not numerous, and with one exception (the southern United States) they are, so far as is known, not very extensive; but they are of peculiar value and importance because the climate is the only one in which two of the modern world's most valuable products, cotton and maize, can be successfully cultivated under natural conditions. The value of regions enjoying the special conditions is, of course, enhanced when the variability of the amount of rain from year to year is small, and the chances of loss from drought or flood correspondingly diminished. We shall see

afterwards that monsoon conditions initially weak are preferable to those weakened (as in India) in the manner deseribed.

The time of the hot monsoon in the Asiatie part of our area is that of the eold monsoon in the Australian part. Remembering that most of this Australian region lies in the belt of the south-east trades, it is only necessary, so far at least as northern and eastern Australia are concerned, to understand that the out-flowing tendency due to high prcssure on land resists the influx of air and deflccts the trade wind to a more southerly direction parallel to the coast: hence there is little rain.

In the intermediate zone, between the continental areas of Asia and Australia, the archipelago is, or would normally be, traversed by the equatorial belt. The equatorial belt itself, and the trade-wind movements on each side of it, are modified to a varying degree by the monsoons, although local monsoonal action is weak, there being only trifling seasonal changes of temperature, and therefore small differences of temperature between land and

sea. The typical double rainy season (p. 92) scarcely occurs. However, as the atmosphere is constantly near saturation, practically any movement, especially near the mountainous islands, produces copious rains. Hence there is no really dry season, and the modified equatorial conditions merge with those of the characteristically monsoonal areas to north and south. The region affected in this way extends far to the eastward (as far as about longitude 145° E., the position of the Ladrone group of islands), and the return to normal conditions out in the Pacific is very slow: hence this region is of great extent and forms the largest oceanic area of heavy rainfall in the world. A striking consequence is the extraordinary freshness of the surface waters of the ocean.

In conclusion, it may be well to recapitulate the characteristic features of a monsoon climate as exemplified in the region we have just described, and we take India as the best-known and most typical part. The year is divided into three seasons: cold-weather, hot-weather, rainy.

Approximately—

> The cold weather lasts from October to January.
> The hot weather lasts from February to May.
> The rains last from June to September.

The transition from cold weather to hot is gradual, from hot to wet sudden, and from wet to cold gradual.

The wet season occurs during the landward monsoon, except locally in districts where the landward monsoon has already been drained of its moisture and the seaward monsoon has crossed a surface of ocean, as on the eastern side of India or the Malay Peninsula.

CHAPTER VII

CLIMATIC REGIONS : TROPICAL

The tropical regions include the belt between the two high-pressure zones, or the two trade winds and the equatorial belt. Under oceanic conditions the climate is one of high average temperature throughout, with considerable steadiness of atmospheric circulation except in the neighbourhood of the great vertical movements, where the winds weaken and become fitful and uncertain, with long intervals of calm. The characteristic features of the temperature variations are the great importance of the diurnal element and the trifling amount of the seasonal changes (p. 20) near the equator, with a fairly rapid diminution of the one, and increase of the other, as latitude increases. Land and sea breezes are therefore of great importance in coastal regions, especially where

the relief of the land favours their development (as at Port Royal in Jamaica, which is backed by the Blue Mountains) and there is comparatively little tendency to monsoonal action on a large scale until the higher latitudes are reached, when it increases quickly.

Since the general movement of the winds is westward, the normal direction will be towards the land on the east sides of the continents and seaward on the western coasts. This is very important, being the opposite to what obtains in higher latitudes. We expect rainfall to be greatest on the east side of the land and least on the west, and in the case of departure from this state of things must seek for monsoonal influence.

The supply of air for the trade winds being chiefly drawn from the descending currents of the horse latitudes, the air is extremely dry to begin with and picks up moisture greedily where it can be got, as over the great oceans; recent measurements by Dr. Lütgens give as a rough estimate a mean evaporation, from a surface of water exposed on board ship, equivalent to removing a layer of about 0·27

inch in thickness daily. When the winds do not pass over a water surface the conditions remain the same as in the high-pressure belt, and the arid area is extended a long way towards the equator, as in the region of the Sahara. As the equator is approached the horizontal motion weakens and the atmosphere becomes more and more sensitive to ascending movement. Sea winds are by this time nearly saturated, and hence there is a considerable area of uncertain rainfall, forming a sort of blurred edge to the equatorial belt. Land winds, on the contrary, are still dry, and the rains only begin when the horizontal motion is lost and the ascending movement of the equatorial belt has definitely set in, with the result that the transition from arid to moist conditions is rapid, as on the southern border of the Sahara (p. 93).

Again, the effect of elevated land in forcing the trade-wind current into higher levels of the atmosphere depends upon the position in latitude, saturation and consequent rainfall being more readily attained in low latitudes than in high. The amount of rain must also

obviously depend upon the height and steepness of the land slope, but as the trade winds are only subject to irregular variations rain falls at all seasons with no definite interval of drought. This is well illustrated in the case of eastern Madagascar; the conditions of such islands in the heart of the trade-wind belt are worth careful examination.

Leaving the northern Australasian region and the region of the Malay Archipelago out of account as being to all intents and purposes entirely under the control of monsoons, we find that the great land masses to be considered are Africa—nearly the whole of it; most of Australia except the north, east and south; the southern part of North America, Central America, and South America down to near the La Plata.

Taking Africa first, the outstanding features which at once command attention are (*a*) the general plateau surface of the continent, with steep edges nearly all round, and for the most part little or no low-lying coastal plain; and (*b*) the absence of any dominant axis of raised land giving a long slope. It is true that the

plateau surfaces are by no means uniform, but ranges or groups of mountains and hills, and even isolated peaks, occur quite irregularly, except in the Atlas region right under the high-pressure belt, and in Abyssinia (p. 143), of which more later on. Africa therefore shows no controlling monsoon region. There is no continental area of the world where the "planetary" circulation is less disturbed or distorted, for it will be understood that the absence of a great monsoon centre on either side leaves the equatorial belt without serious modification or displacement.

The typical equatorial climate, with the double rainy season, is met with over a large part of the basin of the Congo. Within this area the dry seasons are short and not altogether rainless, and with the continuous high temperature tropical vegetation grows luxuriantly. Some special features of the climate of the region, such as the local distribution of rainfall and the diurnal variation in the strength of the wind, are of great interest, but space does not allow of their description here. In the zone of single rainy season (p. 93) a

very marked contrast between north and south is noticeable, for on the northern side, as has already been pointed out, this zone is extraordinarily narrow, while to the south it attains the greatest breadth known. We may merely note here the difference in rate of transition, recurring to the question later on in connexion with the trade-wind belts, and observe the interesting result of the seasonal migrations in producing a double annual flooding of the river Congo, one from its northern tributaries and one from its southern. As many people are familiar with the wettest known part of the world (p. 147) it may be of interest to record that Debundja, in the Kamerun, which lies within this region, enjoys the reputation of having the second highest annual mean rainfall observed. The difference in the conditions producing the results in the two places is significant. In the eastern section of this part of Africa the climate does not conform quite so closely to the equatorial type, the monsoon regions of Asia and Abyssinia making themselves felt indirectly.

In the region of the north-east trades we

have arid conditions carried down to exceptionally low latitudes, rainfall being practically absent until we are close to the limit of migration of the equatorial belt. This is due not to movement of air from Central Asia, as is often stated, though doubtless such movement would have a similar effect if it occurred, but to the fact that no liquid surface intervenes after the air has descended in the anticyclones of the high-pressure belt on the north African coast. The intense heating during summer has but little effect (p 110), and in the dearth of moisture the winds are light, even in the heart of the trade belt. The influence of sloping ground in producing monsoonal currents is probably nowhere better seen than in the valleys of longer rivers not too near the equator, as in the Senegal and Gambia, where a south-west wet monsoon alternates with the north-east trade every year for a time which is longest at the coast and gets shorter and shorter as we proceed inland.

On the eastern sidc the conditions in these latitudes are affected by two factors: (1) the local monsoon conditions due to the Abyssinian

highland; and (2) the near neighbourhood of the great monsoon region of south-eastern Asia. Our knowledge of this area has been greatly increased of recent years by the activity of the meteorological service of the Egyptian Government, but there are still large tracts about which we have little or no information. The general position is, however, that during the winter season the trade wind in the Arabian Sea blows normally almost parallel to the general direction of the coast, so that little or no rainfall would ensue, except locally, in any case. But the tendency towards an outflowing monsoon wind from the highlands deflects the trade wind slightly seaward and makes a rainless period certain. During the hot season the dominant factor is the south-west monsoon, which draws air away from the land in spite of local heating, except where, as in the highland region, the monsoonal action is strong enough to draw away a part of the main current of the Asiatic system and ensure the heavy summer rainfall of Abyssinia which provides for the flooding of the Blue Nile. The White Nile, we note

in passing, gets its water from equatorial rains.

Certain coastal effects, also more or less clearly observable elsewhere, become specially important in this region. The land round the Red Sea is so fiercely heated in summer that notwithstanding unfavourable configuration a weak monsoonal movement occurs along the coasts and over the sea. Temperature is somewhat modified, and even mists prevail, as near Mocha and elsewhere, making parts of the coastal strip the best coffee-growing districts in the world. As the intensity of the heating inland diminishes towards the end of summer, this gentle circulation disappears and the coast regions are hotter, or at least more trying, than before; travellers to India dislike the Red Sea in September even more than in July and August. The continuance of summer heat in this way is marked in many parts of the world, as in the Levant and on the west coast of North America from San Francisco southwards. Its relation to the culture of the vine is important.

Africa south of the equator differs from

Africa north of the line chiefly in its smaller breadth from east to west, its greater average elevation, and its remoteness from the Asiatic monsoon area. The normal wind being the south-east trade from the Indian Ocean, the average condition would be a wet eastern coast, rainfall diminishing towards the west; and this, subject to the local control by the configuration, is very much what occurs. But seasonal variations are introduced by monsoonal action. In the southern winter, pressure over the land is high, and the trade wind is excluded by outflowing air (as in north-eastern Africa), aided perhaps by the simultaneous demands of the south-west monsoon north of the equator. Hence we have a dry season over an area extending from the limit of equatorial rains to a small district in the south-west of Cape Colony, which comes within the "Mediterranean" region. During summer pressure falls, the south-east trade is drawn in, and there are widespread rains, varying, of course, locally in amount, but on the whole diminishing to the westward, and usually almost to zero before the

west coast is reached. The arid conditions on the west coast are intensified and extended northward by the focus of high pressure which persists over the ocean (p. 116), although not at its maximum strength at that time of year: the anticyclonic circulation gives a westerly, *i. e.* off shore, direction to the winds in spite of any indraught that might be due to the heating of the land.

The seasonal distribution of rain, chiefly in summer, is therefore the same as on the outer margin of migration of the equatorial belt, the monsoonal action reinforcing the trade wind, as it were, and drawing it inland, while the plateau configuration—the absence of a great low-lying plain sloping up to a main axis of elevated land—keeps the rainfall moderate in amount except in certain parts of the coast, as in Natal. We have thus a large area with high temperature and moderate summer rainfall, the type which, as we have seen (p. 150), is of exceptional economic value. In Natal the steep rise of the Drakensberg is faced by a low coastal strip, and summer rains are copious, special circumstances also affording

some winter rainfall. We therefore find tropical conditions outside the actual tropics, a somewhat infrequent result which greatly increases the resources of the colony.

In the case of Australia we have to notice that the main land-area begins about 15 degrees south of the equator and extends to about latitude 35° S., and that most of the surface is an irregular low-lying plain extending from the west coast eastward to a mountain axis which runs north and south not far from the east coast. The north and north-east are, as we have seen, included in the area of the north-west monsoon. According to Lockyer, the mean position of the axis of the high-pressure belt lies in about latitude 37° S. during the summer months and in about 32° S. during the winter (cf. Table, p. 90). The anticyclonic pulsations in this belt are very clearly marked, the systems being in general larger when the surface is cold than when it is hot, *i. e.* in winter than in summer. We accordingly find a region in the north-west and west, within the latitudes named, closely corresponding to the Sahara, with a

rainfall of five to eight inches annually in the central desert, increasing to about thirteen inches along the north-western coast. To the north and north-east the amount of rain increases as the monsoon region is approached, but the transition to the area within which actual reversal of the trade wind occurs is variable and irregular. Along the eastern coast a short strip in New South Wales receives a remarkably uniform rainfall in all months of the year; the indraught of the south-east trade is a wet wind in summer, while in winter cyclonic rains are derived from the west-wind belt—a modification of the Mediterranean type of climate to which we shall refer again later (p. 182). (Compare also Natal above.)

From what has been said with regard to the relation of the normal arid region to the region controlled by the north-west monsoon, and of both regions to the mountain axis running along the eastern coast, it will be clear that on the western or inland side of the main ridge, especially in its central part—the interior of New South Wales and western Queensland—there must be an unusually extensive area

specially sensitive to irregular variations of all kinds, especially in the matter of rainfall, and therefore exceptionally liable to drought in certain years or groups of years. It is very important to observe that sueh uneertain areas occur either in the "spheres of influence" between two climatic regions whose boundaries are ill defined, as here, or where the special eharacteristics of a climatie type have been destroyed locally within its area, as in the Deeean (p. 148), rather than in regions where the type features are only weakly developed, as in parts of South Africa, or (as we shall see) thc central United States (p. 198).

Coming now to the New World, we find that the northern part of this region affords a great contrast to Africa. Vast land areas lie to the north and south, but within the trade-wind belt itself there is a great expanse of oeean, broken up in the weather part by Florida and the West Indies and then suddenly to leeward by an almost continuous high ridge which runs westward and northward from the mainland of South Amcrica and widens out into a plateau in Mexico. Along the north of

South America the land rises quickly except in the "gap" formed by the valley of the Orinoco; and behind, to the westward, is the towering ridge of the Andes.

Leaving the northern margin of the belt, roughly the latitude of the coastal strip north of the Gulf of Mexico, out of consideration for the moment, we have as normal conditions a strong trade wind over the sea in which the air is heavily charged with water vapour, so that little cooling is necessary to cause precipitation. Seasonal variation is produced, apart from direct land influence, chiefly by the migration of the belts, for as the equatorial belt approaches the ascending tendency increases, the wind weakens, and rain falls. Thus the trade winds are strongest in winter, and summer is the rainy season; or, as before, "the rain follows the sun." It will be seen that seasonal variation of this type becomes less marked as latitude increases. In the eastern part of the West Indian region the weather-sides of the islands are marked by strong winds and rain at all seasons: the weather is too rough for some tropical crops,

such as cocoa, and the hardier sugar-cane takes its place. Heavy surf beats along the coast. The lee-sides of the islands are more or less protected according to the position and configuration, and the diurnal land and sea breezes and local monsoons become important. The effect of the break in the trade-wind belt, allowing tropical hurricanes generated at sea along the polar margin of the Doldrums during the summer months (p. 95) to re-curve and make their way into the west-wind belt, is also to be borne in mind.

In the western part of this region four factors have to be taken into account: (1) the Gulf of Mexico and the Caribbean Sea, a large extent of surface supplied with warm water from the northern branch of the equatorial current, which provides abundant water vapour all the year round and forms a centre of high temperature in the winter season; (2) the large continental area of North America, hot in summer and cold in winter, and consisting of an immense plain sloping upward on each side to two mountain axes, a low one on the east and a high one on the west; (3) the

continent of South America; and (4) the high narrow axis of Central America and the plateau of Mexico.

During the winter season the high temperature over the Gulf of Mexico causes a relatively low barometric pressure, which is associated with the generation of cyclones. These systems usually make their way north-eastward into the west-wind belt, cutting along the United States sea-board between the Atlantic high-pressure zone (then at its weakest, p. 118) and the continental area of high pressure. The indraught accompanying these cyclones, helped by the relatively low temperature of the land, deflects the trades over the area and produces a general counter-clockwise or cyclonic movement, with winds closely following the general direction of the coast-line. Little rain falls in winter except on the south-western margin of this area, where (as in Honduras) the trend of the coast and the surface relief are favourable. Along the Mexican coast the northerly winds attain great strength; they are known as the "nortes" or "northers," or, when they spread over the

plateau at considerable elevations, as they sometimes do, the "papagayos." Along the Pacific coast winds are light and variable and there is little or no rain.

The summer *régime* in the eastern part of this area will be understood from what has been said already. All round the Gulf coasts monsoonal influence is important, although the coastal region in which it can make itself felt is usually narrow. A noteworthy exception to this is the indraught northward from the Gulf into the central United States. Since the slope northward up the Mississippi valley is very slight, and the mass of raised land which gives the principal monsoon effect lies to the westward, the current from the Gulf is weak, although it penetrates a long way inland into west-wind latitudes. Hence we have a moderate summer rainfall, with high temperature, distributed over large areas in the Gulf States and Texas, as well as along the southern part of the Atlantic coast; and this being due neither to a strong monsoon already tapped and made sensitive, nor to position in a transition region on the edge of a strong

monsoon area, it is fairly certain, and serious droughts are rare.

On the Pacific coast the winds are frankly monsoonal; the trade wind scarcely appears as a sea-level wind on the lee-side of the mountain barrier. There are, naturally, great local variations, but summer is the wet season almost everywhere.

In Mexico the differences of climate due to difference of elevation above sea-level become more important than those arising from difference in latitude. This country is therefore commonly divided into zones of elevation —the *tierra caliente* or hot belt on the coast, up to 3000 feet; next the *tierra templada* or temperate belt up to 7000 feet; then the *tierra fria* or cool belt to 13,000 feet; and lastly the *tierra helada* or snow belt. The centre of Mexico is arid.

In South America the great chain of the Andes stretches unbroken along the western coast, spreading out to a considerable width between about latitudes 15° and 25° S. On the north-east and south-east coasts are highlands, separated almost on the equator

by the great opening of the valley of the Amazon which extends westward some two thousand miles across the continent, almost to the Andes. The normal position here is of course north-east and south-east trades, with the equatorial belt between. In the low latitudes there is very little monsoon effect, but in the higher latitudes this becomes very marked, so that after each solstice the region on the side of the equator near the sun becomes, as before (p. 168), a centre of weak wind and ascending air, the opposite trade wind being strengthened and drawn towards it. Thus "the rain follows the sun," and over the upland areas north and south the rain falls in summer, the winds being drawn in to a nearly easterly direction. Between the two trades the equatorial belt is in this way expanded and its boundary becomes ill defined. The sharp edge becoming unrecognizable, there is practically no region having a double rainy season—the typical diurnal rainfall is merely spread over a wider band, and varies in intensity with the season. This climate which is experienced

over the greater part of the basin of the Amazon has been well described as having rainy seasons with breaks in the rains, and dry seasons with occasional showers: under favourable conditions, as at Para, it is one of the most healthy and agreeable to be met with in the tropics.

Along the coast from Pernambuco southwards the south-east trade brings rain at all seasons, the amount varying with the seasonal distribution of pressure over land and sea. It is interesting to compare this, the greatest coffee-producing region in the world, with the eastern coasts of Africa and Australia in the same latitudes, noting the different ways in which the three are affected by monsoonal action.

In the inland areas of summer rainfall we observe that as soon as we reach the lee-sides of the uplands the rain is comparatively small in amount, even where there are openings to the coast as in the Orinoco and La Plata. Heavy rainfall, in fact, only occurs in the equatorial region. The mouth of the La Plata comes in the region of the high-pressure

belt, and the conditions beyond this southern part at any rate resemble those in the inner slopes of the mountains in New South Wales (p. 166), with somewhat similar vicissitudes in the way of destructive droughts.

In the high regions of the Andes the climate is mostly arid except near the equator. Quito has been described as having a climate of perpetual spring—the temperature being low because of the great elevation, and seasonal changes slight because of the latitude. But the great diurnal range of variations continues, and the perpetual spring is, as has been well said, really an average of daily samples of spring, summer, and winter.

The Andes form a practically complete barrier to surface winds from the east, and the narrow west-coast strip has only light summer rainfall of the monsoonal type, varying locally (compare Western Australia in the same latitude, p. 165). An interesting example of the effect of ocean currents occurs off the coast of Peru, where the cold water of the Peruvian current (a stream current derived primarily from the west-wind drift, but in all probability

assisted by the area of high atmospheric pressure just off the coast) causes sea-fogs of a frequency and density only surpassed off the Grand Banks, where the Gulf Stream meets the Labrador Current. These wet fogs drifting inland are known in Peru as "garuas," and provide a quite considerable supply of moisture in some districts which have but scanty rainfall.

CHAPTER VIII

CLIMATIC REGIONS: SUB-TROPICAL AND TEMPERATE

The principal factors controlling the distribution of climates in the sub-tropical and temperate zones have already been dealt with at some length, and in discussing them we have drawn illustrations from a considerable part of the regions included. The position may now be re-stated from the geographical point of view, and certain gaps filled in.

Beginning with the region on the polar side of the axis of the high-pressure belt, it may be pointed out again that the high-pressure belt itself is for the most part made up of anticyclonic systems of oval shape, which have their longer axes pointing east and west, travel eastward at varying speeds, and are constantly changing in intensity, dying out and re-forming. It is no easy matter to

follow the progress of individual systems from the beginning of their career to the end, especially over the oceans, and there is still some diversity of opinion amongst authorities as to whether the constant eastward procession extends completely round the circumference of both belts or not. Possibly in some parts there may be permanent single high-pressure systems, but it is difficult to draw a line between the strengthening and weakening of one stationary system and the pulsations due to the passage of several. What matters to us is that if there are separate oval anticyclones following one another, then, on the polar sides at least, there must be V-shaped barometric areas between, which form wedges of low pressure projecting out from the west-wind region. The diagram of isobars for part of the northern hemisphere in Fig. 9 will make this clear, the V-shaped areas being shown at A and B. The general weather conditions are those of cyclonic systems (p. 102), with sudden change of wind direction along a central line; they form a very characteristic feature of the climate in

the southern parts of Australia, where they are known as "southerly bursters," and it may be suggested (although the matter has not, so far as we are aware, been fully investigated) that some of the phenomena associated with the "Khamsin" and "sirocco" winds

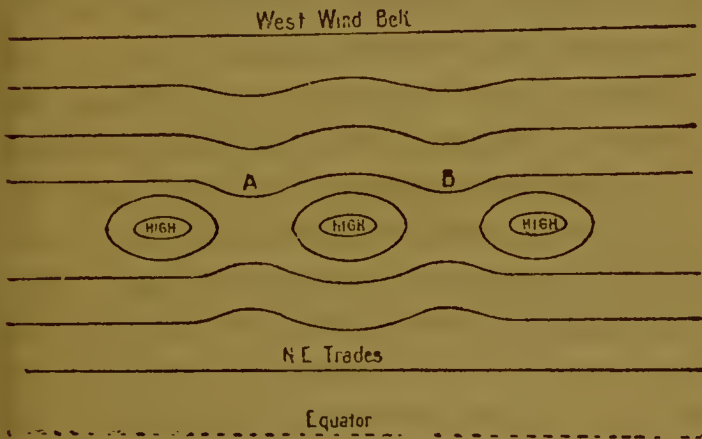


Fig. 9.

of northern Africa arise in a somewhat similar way.

But, whatever the arrangement of anticyclones in different parts of the belts may be, it seems clear that the high-pressure axes are almost always continuous. It does happen that the succession is broken so as to admit

of the V-shaped valleys (A and B, Fig. 9) penetrating into the trades and linking up the west-wind belt and the regions near the Doldrums, but this is abnormal and of rare occurrence, except where the surface circulation is broken by a high ridge of land running north and south with a heated plain to the east of it, as in North America.

Little need be added to what has already been said about the distribution of regions having the "Mediterranean" type of climate. During the summer season they are under the high-pressure systems, and light winds and drought persist with a completeness and for a length of time which depend upon the nearness to the central line of the anticyclones and the breadth and depth of the intervening Vs. Along the north of Africa, for example, the summers are of great length and the drought is unbroken, but along the European coast of the Mediterranean the type becomes less perfect as we work inland. Here the *lateness* of the summer as compared with higher latitudes is remarkable, the northward migration of the belt lagging long behind

the solstice (p. 90). Spaniards and Italians wear overcoats long after Britons have discarded them, and resume them much later. The "west-wind season" being longer to the north than to the south of this region, the rainy winter is longer, and hence also the total annual rainfall greater. The winter cyclones being in large part derived from the Atlantic, the rainfall diminishes from the west eastward until the amount received in the extreme parts of Persia and northern Arabia is quite small. The importance of the *type* of distribution continues, however, to be very great, and the delimitation of the Mediterranean region by the criterion of climate, in contrast to other regions whose boundaries are better fixed by water partings, mountain axes, or otherwise, is a matter of much economic and historical interest to the geographer.

The conditions in other land areas within the appropriate latitudes are for the most part somewhat different from those in the Mediterranean. It must be understood that the type is only likely to be reproduced on the western sides of land areas, for there the

summer wind from the east is a dry wind. On the eastern sides the summer trade wind is a sea wind, bringing rain, and the winter west wind, although in some sense a land wind, is probably cyclonic and therefore also rain-bearing, so that rain will fall at all seasons. In Asia the type is entirely obliterated by the monsoon conditions. North and South America have narrow coastal strips on the Pacific slope where the normal type is developed, but extension eastward and inland is prevented by the high mountain axes; on the Atlantic or eastern sides the weak monsoonal conditions (p. 171) bring rain in summer in addition to the cyclonic rains of winter. South Africa and Australia just reach the west-wind belt in winter, henee a small district round Cape Town, the south of West Australia, and the south of South Australia have the typical winter rainfall, while the district round Port Elizabeth in Africa, most of Victoria in Australia, and northern New Zealand reeeive rain at all seasons.

By what amounts, as we have seen (p. 101), to a well-marked transition, the region affeeted

by the migration of the great anticyclone belt merges with the zone of permanent eastward drift. The standard condition, from which we have to consider departures, is that which finds its strongest expression in the Great Southern Ocean, where along a belt having its axis in about lat. 60° S., and extending to the coast of the Antarctic continent, deep cyclones follow one another eastward in quick succession. On the advancing side of these cyclones relatively warm air will blow in from lower latitudes, and in rear of the trough of lowest barometer cold air will be drawn from higher latitudes. As this air ascends in the central area rain will fall—the maximum fall being, so far as appears, somewhat in advance of the centre of rotating wind, and to one side of it. In this southern zone the mean pressure varies normally, *i. e.* it is higher in winter than in summer, but the average gradient does not change much, and the cyclones vary but little with the seasons in number and intensity. Winds are strong, and stormy weather is frequent, especially in the higher latitudes. Rain falls at all seasons.

The only land areas which come within this belt are the southern parts of South America and New Zealand. In each case there is high land running north and south close to the west coast, and the rainfall to the west is accordingly very heavy. East of the mountain ridges the rainfall is much less (p. 127), and in South America, where the ridge of the Andes is high and continuous, much of the country becomes a desert of shingle. The Canterbury Plains of New Zealand enjoy a climate much resembling that of parts of the British Isles.

The corresponding latitudes in the northern hemisphere are in strong contrast, from the fact that the land area is very large. Mention has already been made (p. 118) of the effect of this in reversing the seasonal variations of pressure over the northern Atlantic and Pacific oceans, cyclones being deepest, and therefore most productive of stormy winds and rain, in winter, at which season their eastward progress over the land is most likely to be interfered with by the stable high-pressure areas over the cold land. In summer

the relatively low pressure over the land gives freer access to the ocean cyclones, but these are less numerous and shallower, and usually move about less actively. Primary cyclones, not being convectional in their origin (p. 104), may be generated within a land area even in winter, but this is usually confined to places where the surface configuration gives rise to special conditions of temperature and air movement, as in the plateau region east of the Rockies in North America.

Hence, speaking quite generally, we have in the land areas of the northern hemisphere two distinct types of temperate climate: the *oceanic*, in which the range of temperature is small and rain falls at all seasons, but with a well-marked cyclonic maximum from the winter storms; and the *continental*, with a great difference of temperature between summer and winter, short springs and autumns in which temperature rises and falls quickly, and little wind. In the continental climate primary cyclones, with their comparatively rapid movements of translation from place to place, do not usually bring much rain; the

rainfall comes chiefly from local disturbances of the secondary or "thunderstorm" type, which develop most frequently with the unstable conditions of rising temperature and falling pressure characteristic of spring and early summer. The annual rainfall is small in amount, and falls at all seasons, but by far the greater proportion during the warm months. In Siberia about 70 per cent. of the annual rain falls in spring and summer, 22 per cent. in autumn, and only 9 per cent. in winter (Supan). It is to be noted that most, if not all, of the winter rainfall occurs in the form of snow, and that snow sufficient to form a deep covering corresponds to only a comparatively small amount of water. The ratio usually accepted is that of 12 to 1, a foot of snow yielding, when melted, about an inch of water, the equivalent "rainfall" recorded.

The oceanic type of climate is best exemplified in the west of Europe, especially the British Isles and Norway, and on the coasts of British Columbia and Alaska. In Scandinavia and Britain the oceanic qualities are quickly "discharged" by the high land

(p. 128), and in Sweden and eastern England the continental type is already approached to such an extent that, although there is rain at all seasons, the wettest months occur in summer; the winter cyclones are drained but not dry, and the shallow summer cyclones favour secondaries and "thunderstorm" rain. France has similar transitional phases, and it is only when we get east of the Alps, in a line through eastern Germany and Austria, that the continental type may be said to be fully established. Beyond this is the great continental stretch through Russia and Siberia to the Pacific coast.

Although the variations of all the climatic elements in this region of western Europe are comparatively small, it can easily be understood that, depending so largely as they do upon the number and intensity of the cyclones coming from the Atlantic, they occur with great irregularity and uncertainty from day to day, from season to season, and from year to year. Hence what may be called the "weather" features of the climate are of unending interest and importance, and the

problem of weather forecasting is one of peculiar difficulty. If, as is likely (p. 105), the cyclones and anticyclones of those regions merely represent eddies set up between air currents moving in different directions, then the chance of our being able to predict the birth of a system of either type at any particular place or at any particular time seems small. Up to the present we are not able to predict the path of individual systems after their existence has been recognized except by quite empirical methods based on a general knowledge of their usual habits. Dependence is chiefly placed upon "synoptic charts," which show the surface distribution of pressure, temperature, wind, etc., over the area considered, at some particular time. These reveal the relative positions, sizes, and intensities of the different systems at the moment of simultaneous observation, and comparison with a similar chart of some few hours before enables an experienced forecaster to predict the weather changes likely to follow from probable changes in the systems. Forecasts of this kind can only be made for two or three days

ahead at the most, but the degree of accuracy attained under modern conditions is extremely high. Since most of the systems in question approach Europe from the Atlantic, it will be seen that the British Isles are affeeted by them first, and are therefore able to render timely service to the Continent. The intro-duetion of wireless telegraphy has helped matters by making it possible to extend the charts westward, or at least to give longer dangerous warning of the approach of dis-turbances to navigation.

While the tracks of low-pressure systems are subject to very great variation, there arc two main lines along whieh they movc, or upon the course of which they are generated, to such an extent that these lincs may be regarded as dominant features of the situation. Both start from a point off the Newfoundland Banks, near the confluence of the Gulf Stream and the Labrador current, and after running eastward together for some distance one bends northward and thcn again eastward, forming the lane of persistent low-pressure known as the "Ieeland depression" (see Platc 3), and

extending along the north of Europe not very far from the coast. The second keeps its easterly direction longer, and then turns southward towards the Mediterranean. Seasonal variation in position is marked by the fact that the two lines are farther apart in winter than in summer. In winter the cold land keeps the first branch northward, and the second actually follows the line of the Mediterranean; but in summer the first branch crosses the continent and bends south-eastward, while the second is kept north of the Mediterranean by the high-pressure belt.

In the great continental region of Eurasia the most marked feature, apart from the great range of temperature, is the seasonal distribution of the rainfall. The southern part of the area, north of the region of the Tarim, the aridity of which results from the joint influences of the high-pressure belt and the surface configuration, has a scant rainfall falling almost wholly in summer. Farther north comes a belt with more rain, not so severely restricted to the summer season, and

farther north still another belt of scanty rain fairly equally distributed over the year. The cause of this is doubtless to be found in the fact that some of the cyclones of the northern line described above make their way far eastwards, adding their rain to that of the continental type.

It is useful for many purposes to note the relation of the four types of climate which we have found in Eurasia. Drawing a line roughly from the Baltic to the Persian Gulf, the regions to the north and east have wet summers and dry winters either from monsoon or continental climates, the boundary being sharply drawn in the arid barrier country in the west, but less definite in the higher latitudes to the east. West and south of the line we have, on the whole, dry summers and wet winters from the Mediterranean and oceanic types, the distribution becoming more uniform as we go westward and northward.

Turning now to North America, we find the area of oceanic climate much restricted by the outline and configuration of the land.

Mountains keep close to the coast, which sweeps round to the westward in Alaska, so that instead of the wide opening of the Norwegian Sea from the Atlantic we find an almost impassable barrier. The moderating influences are therefore lost almost before latitudes equal to that of the north of Scotland are attained, but all along the coast, from British Columbia northward, the climate is ultra-oceanic, with heavy rainfall nearly all the year round and constant dampness. The cyclones of the Pacific, probably in consequence of this configuration, vary somewhat less in their tracks than those of the Atlantic, and it would appear that, perhaps because of the neighbourhood of the great monsoon region to the usual place of origin, the summer minimum of cyclones is more marked, except when the typhoons of the China seas (p. 95) make their way into this belt. The chief winter track—there is only one really distinctive—starts near Japan, touches Kamschatka, and closely follows the parallel of 50° N. to Vancouver Island. But it does not end here, for, notwithstanding the

elevation of the western mountain and plateau system and the low surface temperature, many of the cyclones, after discharging much moisture on the Pacific slope, continue their eastward way right across the continent. The summer cyclones can rarely be traced over land in the same way.

It is necessary, in order to understand the peculiarities of climate of the rest of North America, to have in mind the main features of the western mountain system as they would appear, for example, in a typical section drawn from west to east. First, we have the Coast Range or its equivalent, sloping up steeply from the ocean. Next comes a series of long, narrow valleys, enclosed between the Coast Range and a parallel mountain system represented by the Sierra Nevada or the Cascades. East of this comes a wide plateau tract diversified by ranges of low hills, and known from south northward as the Colorado plateau, the Great Basin (an arca of inland drainage), the Columbia plateau, the interior plateau of British Columbia, and the Yukon plateau. Finally, there is the main system of the

Rockies. On the whole, the mountains west of the plateau region increase in elevation from south to north, and we must note again that they swing round to a westerly direction in Alaska. The Rockies, on the other hand—the term being restricted to the most easterly member of the system—diminish in general elevation from south to north, terminating in the Endicott Range, west of the mouth of the Mackenzie river.

Prevailing westerly winds will obviously afford rain to the western slopes of each of the three ridges, and elsewhere the rainfall will be scanty. Temperature varies with the seasons through a wide range, so that the climate is one of extremes, but the diversified surface and the "grain" across the main trend of atmospheric motion do not lend themselves to the formation of a homogeneous area of high pressure during winter, as in Eurasia. Hence, as we have seen, cyclones from the Pacific make their way across the continent during the winter months, although they only distribute rain in certain parts. Associated with them are high-pressure areas or anticyclones, which

must obviously also travel eastward. During summer few cyclones come from the Pacific, and most of the intensely heated region is converted into a low-pressure area with ill-defined cyclonic circulation, in which a small rainfall is distributed by local depressions. Thus we have within the mountain districts a fairly abundant rainfall without strictly marked seasonal variations, and in the plains and in the valleys light or scanty rain. The feature is of peculiar interest in the Colorado plateau, where large rivers draining from the Rockies make their way across arid plains.

The climate of North America, east of the Rockies, is chiefly determined by three factors: the western mountain system, which deflects the eastward atmospheric movement to such an extent as to constitute a fairly effective barrier to influences from the Pacific; the large open continental area of northern and north-western Canada, serving chiefly as an inexhaustible reservoir of cold air; and the Gulf of Mexico, supplying unlimited warmth and moisture. To these we may add, as of importance in the north-east

and east, the Atlantic and its extension in Hudson Bay. The Appalachian system, although of great importance locally, is of only moderate height, and as its trend (south-west to north-east) is nearly parallel to the direction of winds arising from large continental areas of high or low pressure and of the tracks of smaller moving systems, its influence scarcely ranks in the same plane with the others.

Take the winter season first. Pressure is, on the whole, highest in the west, over the mountain region; and to the north and east of this, in north-western Canada, the land is open beyond the Arctic circle. Temperature everywhere falls very low, and hence we have a current of cold dry air from the north-west making its way into central Canada. To the south and west of this lies the plateau region east of the Rockies, still low in temperature, but ending in the warm, vapour-laden area of the Gulf of Mexico down in the trade-wind latitudes. Not only do the oceanic systems cross from the Pacific, but in the lee of the mountains fresh cyclones and anticyclones

are generated as eddies in the easterly currents above. In the northern part the cyclones bring little or no rain, but in the south, cyclones being fed with moisture from the Gulf, considerable rainfall occurs. The general movement is eastward and north-eastward; all tracks, in fact, tend towards New England and the starting-point off the Grand Banks in the Atlantic (p. 189). The rotating movement in all these systems gives rise to rapid variations in temperature and humidity. With the eastward motion we get cold, dry, northerly winds in the front of anticyclones and the rear of cyclones, alternating with warm, moist southerly winds in the rear of anticyclones and the front of cyclones. This effect is most marked in the central parts of the United States and the Atlantic sea-board, the latter combining in some parts, as near New York, many of the more doubtful advantages of both oceanic and continental winter climates. Note also the relation to the "northers" of Texas and the Mexican coast (p. 170). North of New England the easterly winds on the north sides of the cyclones are

sea winds from the Atlantic, and rain or snow falls in the St. Lawrence basin up to and beyond the Great Lakes.

During the summer season the active influence of the Pacific is, as it were, in abeyance for the most part. The land surface becomes greatly heated, and the plateau region east of the Rockies more prolific in cyclones and anticyclones than before. There is now, however, a monsoonal indraught of moist air from the Gulf of Mexico (p. 171), and in consequence we have not merely the normal continental summer rainfall but that derived from the extra vapour as well, and the whole region, excepting only the extreme west, gets moderate but not excessive supplies well distributed in the late spring and the summer.

To sum up: in this region, by reason of the open country to the north, the mean temperature for the year falls quickly as latitude increases. In the north and north-west the winters are long, very cold, and dry, with much bright calm weather, and the summers short and hot, with adequate rain. In the west the range of temperature is extreme,

the winters dry, and the summer rainfall scanty. The southern and eastern parts of the region—roughly that east of a line drawn from the north-west corner of the Gulf of Mexico through Lake Michigan to the south of Hudson Bay—receive a moderate amount of rain at all seasons, the amount diminishing, on the whole, from south-east to north-west, but, notwithstanding the large amount of moisture present, great variations of temperature are apt to occur suddenly, even along the coast, in consequence of changes of wind direction.

Two points may be noted, in conclusion, as of peculiar economic importance. First, the extreme fluctuations of temperature which occur from day to day introduce great uncertainty over a large part of this area with regard to the dates of first and last occurrence of severe frost in each year. Second, practically the whole of this vast region lies in one planetary belt, and the normal conditions therein, although profoundly modified, are not destroyed or reversed; hence the variations, however great thcy may be in one year,

are rarely excessive when we compare one year with another. This, thanks chiefly to the Gulf of Mexico, is specially true of the rainfall. There is no record of widespread famine in North America due to failure of the rains.

CHAPTER IX

CLIMATE AND VEGETATION

In a general description of the chief types of climate special stress has been laid throughout upon the temperature of the air and its changes, and on the amount and seasonal distribution of the rainfall. This has been done not merely on account of the physical nature of the problems dealt with, but also because these are the factors which specially influence the distribution of man and his activities in different parts of the earth. The influence is not as a rule direct, for, given a supply of food, man can exist in practically all climates; it is only indirectly through the food supply that the numbers and modes of life of the inhabitants of any region are regulated by climate. The intermediate agent is vegetation, which responds at once to climate, for in this respect we may regard the animal world as merely forming a means of collecting

food for man. Man may eat animal food, and the animal eaten may subsist upon other animals, but eventually we must come to some animal which lives upon a vegetable diet. What usually happens under modern conditions is that such meat-providers, as cattle or sheep, devote their whole time to the collection of vegetable food in districts where the supply is so scanty that man himself is unable to gather it in sufficient quantity; the land will not yield a "crop" and is therefore used for "grazing."

We propose now to examine some of the principal features of the relations which exist between climate and vegetation under natural conditions, to indicate their effects upon primitive man, and then in a final chapter to trace a few of the ways in which civilized man has modified the conditions of vegetation in different climates, since he has not yet discovered any means of modifying climate. It may be explained that the term "civilized man" is used to mean man who has acquired thc art of modifying his environment, as opposed to uncivilized man, who

merely enjoys its natural advantages; and without reference to any artistic or literary achievements. The reader will find the matter fully explained in the volumes on *Modern Geography* and *The Dawn of History* in this series.

In considering the vegetation of any region we have to deal chiefly with two features, abundance and variety. The flora of one district may consist of luxuriant growth of plants of quite a small number of different kinds, while in another the growth may be sparse but the number of species of plants very large. Again, we have to observe that when we say that vegetation responds at once to climate, we state a result of experience. We do not mean to imply that the vegetation of any region depends upon climate alone. The chemical composition of the soil is of great importance, and attempts have been made to make soil constituents a basis for classification of vegetative regions, or subdivision of regions in a classification based on climate. The results have not been found susceptible of very general application, but in relation to

climate we notice that a plant will often grow in a soil which thoroughly suits it even when it does not find the climate altogether satisfactory. Larch trees, which grow in practically any soil on the Carpathians, will, in western Switzerland, only grow in soils derived directly from crystalline rocks. Another factor which complicates matters, is the varying degree of what, for want of a better word, we may call the *adjustment* of certain plants. The "big tree" (*Sequoia gigantea*) of California belongs to a genus of which only two species survive, and they are probably slowly dying out, but we know that under different climatic conditions in time past, some twenty-six species flourished over a large part of North America. Again, such plants as the Rhododendron and the Evening Primrose have been introduced into Europe within recent times. They have escaped from gardens and entered successfully upon the struggle for existence in the wild state; but it is impossible to say beforehand how far they will spread or what plants will succumb under their invasion.

Subject to these limitations, it is still possible to establish certain quite simple relations between climate and plant life, and it is remarkable how closely the relation holds with regard to the two elements, temperature and rainfall. For it must be remembered that by " temperature " we mean the temperature of the air observed in a shaded screen at a height of four feet above the ground, and this has to be taken as a measure of not merely the temperature to which plants are exposed, but of the effects upon them of solar rays suffering varying amounts of " selective absorption " (p. 74). Evidently most plants are indifferent to quite large variations in the proportions of " light " and " chemical " rays, for we can grow tropical plants in cold climates by merely providing greenhouse heat; it is not necessary to add rays of short wave-length artificially. Again, " rainfall," *i. e.* the quantity of water collected in the rain-gauge, is taken to measure the moisture retained in the soil and available for vegetation, and also the relative humidity of the atmosphere, controlling the loss of moisture by the plants

through evaporation. Here, also, wide variations are permissible, for many natives of warm, moist climates will grow in hot countries where the climate is arid, if only moisture is supplied to the roots by irrigation.

It is possible to arrive at quite definite and useful conclusions about individual plants and groups of plants by precise examination of the limiting conditions of climate under which they will thrive naturally, or can be successfully cultivated. Much has been done in this direction, and some of the results appear on maps or tables giving minimum temperatures for cultivation of, *e. g.* the vine, wheat, and so on, or the minimum rainfall necessary for growing rubber-producing plants. But the subject has scarcely been more than touched, and unlimited fields of research are open. We shall here deal only with the most elementary stages, in which it is unnecessary to give precision to conditions of temperature or rainfall by stating numerical values, or to conditions of vegetation by specifying individual plants or groups of plants.

For it is found that wherever the relation

between temperature and rainfall is such that moisture is always or nearly always available in the soil, the natural vegetation is of the kind in which the plants grow on from year to year or are *perennial*. The representative form of this is the tree, and these regions are distinguished by natural forest growth. Where the relation is such that during some part of the year moisture is so deficient that plant growth, or rather plant existence, is impossible, then during the moister period the plants germinate, get through all the processes necessary for producing a seed which will retain its dormant vitality under great extremes, and themselves die when the conditions become insupportable. Thus vegetation starts afresh every year, or it consists of *annuals*, of which by far the most important representatives are to be found among the grasses. We therefore obtain the first main division of the land surface into forest regions and grass regions. But we note again that the question is not one of the absolute temperature or amount of rainfall, but of the relation of one to the other. The higher the temperature the

more moisture is necessary for the growth of certain plants, and the lower the temperature the less the supply of moisture required—because evaporation is less—until a degree of cold is reached which stops vegetation altogether. Hence there are two types of region with no vegetation at all: the *dry* desert, which has too little moisture in relation to the temperature; and the *cold* desert, in which there may or may not be plenty of moisture, but the temperature is too low for plants of any kind to flourish.

It is to be expected that the change from one set of conditions to another will in general take place slowly, forest regions merging into grass regions and grass regions into desert. Exceptions to this rule are of two kinds: first, those where the configuration of the land causes a sudden extreme change in the rainfall, so that, for example, a mountain range is forest-clad upon one side and arid upon the other; and, second, those where vegetation fails through cold. In this second case the forest growth will become more and more stunted as the climate gets colder, though there

is no lack of moisture to induce a change to the grass type; transition to cold desert conditions may in fact take place directly from the forest. Where the climatic change takes place slowly, vegetation also changes gradually. Between forest and grass the tree growth becomes more and more sparse and irregular, the grass is rank and heavy, and as the dry desert is approached the grasses become lighter and thinner. Many plants of specialized form occur in such regions—the Cactus and Eucalyptus and Olive withstand drought by storing up water, or minimizing loss by evaporation by reducing their leaf surface, while other plants send roots deep down into the ground in search of moisture. Along the margins of cold deserts, mosses and lichens grow in the raw, wet climate. It must, however, be remembered that the advantages which enable specialized forms to survive under conditions of cold or drought may not prevent their flourishing under moister or warmer conditions; many alpine plants will grow in lowlands, and the vine in cleared forest regions of the temperate zones.

With the vague definition of vegetative regions which is all that is easily attainable, but which is sufficient for our present purpose, it is useless to seek for precise numerical boundaries for the corresponding climatic divisions. We may classify regions according to temperature as hot, temperate and cold. With regard to rainfall we may further assume that a high annual rainfall means such a dry season as is either so short or so much broken up by occasional rains that plants are able to live through it. Hence we may arrange regions into three groups according as the rainfall is abundant, moderate or deficient. This gives a cross division which may conveniently be represented in a table—

Rain		Abundant	Moderate	Deficient
Temperature (Equivalent to Latitude)	Hot	(1) Forest (Tropical)	(2) Grass (Savanna)	(3) Desert (Dry)
	Temperate	(4) Forest (Temperate)	(5) Grass (Steppe)	(6) Desert (Dry)
	Cold	(7) Desert (Cold)	(8) Desert (Cold)	(9) Desert (Cold)

From the distribution of the chief climatic

regions it is clear that of these divisions No. 1 represents the wet region extending on both sides of the equator within the belt of double rainy seasons and into the zone of single rainy seasons beyond, to a distance determined by the length and intensity of the dry season. It will also include such parts of the monsoon areas as satisfy the same conditions, and we observe again that the existence of forest may be in some cases a survival from an earlier epoch in which the rainfall was more uniformly distributed than it is now (p. 147). The hot grass area (No. 2), generally known as *savanna*, from the typical region in the highlands of Brazil, usually forms a belt on either side of No. 1, and merges into the desert of the high-pressure zone represented by Nos. 3 and 6, which are continuous, the mean temperature merely falling slightly as latitude increases. On the polar side of the desert we come to the second grass region (No. 5), which gets the name of *steppe*, from characteristic areas in south-western Asia. This region includes some parts having a Mediterranean type of climate, but much the larger portion

consists of the continental temperate type with rain chiefly in spring and early summer. With more uniform distribution of rainfall and falling temperature, due to higher latitude and a more oceanic type of climate, the grass vegetation gives way to the temperate forest (No. 4), transition being effected through a zone of *deciduous* trees, which have some of the seasonal characteristics of the grass region, to the region of *coniferous* trees, which require plenty of moisture but flourish in comparatively low temperatures. The transition to cold desert (7, 8 and 9) may of course occur from 4, 5 or 6, but that from 4 is the most common.

1. *Tropical Forest.*—The largest areas of tropical forest are the normal and modified equatorial belts of Africa and South America and those parts of the Asiatic monsoon area which either receive rain from both monsoons or get such large quantities from the landward monsoon that the soil, aided by the forest growth itself, retains enough moisture to maintain luxuriant vegetation throughout the year, as on the Malabar coast of India, in

Burma, and on many islands of the Eastern archipelago. The characteristic of the vegetation is its rank abundance; the forest is almost impenetrable, the trees being interlaced with climbing plants (lianas) of all kinds; tracks and clearings are grown over again almost as quickly as they can be cut, and in the primeval forest light is almost excluded by an unbroken canopy. Since seasonal changes are scarcely noticeable, there are no special times of flowering, fruiting or seeding. Plants, and even parts of plants, rest when it seems good to them, while others are in one or another of the different stages of vegetative activity.

No civilization having grown up in those regions, practically all tropical plants are "wild," for the invasion of those parts by civilized man from elsewhere is too recent for any serious impression to have been made by cultivation, and the supply of labour presents an almost insoluble problem. There work for livelihood is unnecessary, and the only form of "wages" appreciated consists of such luxuries as beads, brass wire and cotton-cloth

—the demand for which is soon exhausted—and firearms or alcoholic liquor, which requirements are less readily satisfied. Certain wild plants are nevertheless extensively cultivated in the sense that they are given artificial advantages in the struggle against others. The most important are some of the many kinds yielding rubber, notably the *Hevea brasiliensis*, from which Para or Brazil rubber is obtained, and the *Cacao theobroma* or cocoa plant (not to be confused with the coco-nut palm). Of timber trees it is remarkable that there is none yielding a serviceable easily-worked wood, with the possible exception of mahogany. Teak has advantages for ship-building and some other special purposes, but all the others appear to be either so soft and spongy as to be useless, or so hard and heavy as to be unworkable except for "ornamental" purposes. Many plants, including some of economic value such as cacao, flourish best under the shade and shelter of others taller than themselves; hence in cultivation the system of "catch-crops" of some rapidly growing plant is important. In the West

Indies situations exposed to the rough trade winds are used for the sugar-cane, and cacao is grown on the sheltered lee-sides of the islands (p. 168).

In some parts of the areas of the monsoon type where the rainfall, although abundant, occurs mostly in one season, the drainage due to the slope of the ground may cause the soil to become so dry at certain seasons that forest growth is not luxuriant, but the conditions are favourable to bush growth. The most valuable of the economic products in such regions are coffee and tea. Coffee requires a higher temperature than tea, and can withstand only a very small amount of frost; the largest area available for its production is the coastal slope of Brazil, south of Pernambuco (p. 174). Tea is more of a sub-tropical plant, and is not injured by a certain amount of frost; it is largely grown in southern China, Assam and Ceylon.

2. *The Hot Grass Regions or Savannas.*—Here we find a great seasonal variation of rainfall, although the variation of temperature is comparatively small. Trees become scarcer as

the distance from the tropical forest increases, and the type changes to forms able to withstand long drought. In the moister regions grasses are heavy and grow to a great height, and with the woods produce the dense "jungle" which is the congenial haunt of the larger animals, to whom the almost impenetrable equatorial or monsoonal forest is somewhat inconvenient. Towards the desert the vegetation becomes more of the nature of "scrub," and almost the last survivor is the alfa or esparto grass, now largely used in the manufacture of paper. In both savanna and steppe regions the soil is often of great fertility, especially in the drier parts, for since the type of climate is usually associated with level plains or plateaux the surface drainage is not rapid, and the soluble constituents, which are rich in plant food, are not washed out of the soil.

The breadth of this zone, separating tropical forest from dry desert, varies enormously. Africa furnishes the best examples of both narrowness and width. The northern belt, including parts of Nigeria and the southern

Sudan (p. 93), is probably the narrowest, and the whole of Southern Africa the widest. In Australia and North and South America the configuration of the land, with the raised axes running north and south, modifies the distribution according to latitude, and substitutes a north and south distribution, with the result that the savanna areas occur either in isolated patches, as in the llanos of the Orinoco, or in strips on the lee of the mountain ranges, as in south-western Queensland. Again, monsoonal conditions may arise which give vegetation of a savanna type, as in the Dcccan, where the south-west monsoon has been drained before arrival (p. 148), or a zone of moderate summer rain may be extended part of the way across the dry desert belt to meet the steppe region, forming a continuous line with it, as in Texas and Argentina. The liability of savanna regions, where from any cause they attain great breadth, to severe drought, has already been explained (p. 148). We must, however, recognize them as amongst the most important of the undeveloped regions of the world, for not only are large

areas available for cultivation of food products which have hitherto been chiefly confined to the temperate steppe, but in many places, as parts of Nigeria and Uganda, there is high summer temperature associated with moderate rainfall in the manner which is favourable to the cultivation of cotton and maize.

5. *The Temperate Grass Regions or Steppes.*—On the dry margin of these tracts, we find conditions very like those which obtain on the dry side of the savanna, except, perhaps, for a somewhat lower mean temperature and greater range of seasonal variation. The case in which the desert belt is absent has already been mentioned, and where this happens it is practically impossible to draw any dividing line. The first vegetation in districts where regular rain sets in has the same general features. Alfa grass is widely spread, as in Algeria, and then follows the varied flora of the steppe, represented at its best in south-western Asia. Growth begins as soon as the rainy season sets in; the ground is presently covered with a rich carpet of flowers, but as the heat increases and drought ensues,

the grasses wither and die down, leaving a crop of natural hay and distributing seeds which are indifferent alike to the heat and to the cold which may follow, and remain dormant till rain falls again. The course of events varies considerably with the type of climate. In the Mediterranean region growth begins with the winter rains; no great cold is experienced, and the seed has only the drought of summer to contend with. Where the climate is of the extreme continental type, the active season is spring and early summer, and the heat of late summer is quickly followed by excessive winter cold.

The moister part of this natural grass region supports the heavier grasses, and we meet the outposts of the temperate forest belts, the breadth of the transition zone again depending largely on the configuration of the land.

Africa contains practically no steppe country of the temperate continental type. Most of South Africa is properly savanna, except a strip between Cape Town and the Kalahari surrounding the corner where the Mediter-

ranean type of climate is experienced. In northern Africa the coast strip receiving rain is narrow, but on the plateaux to the south of the Tell the ground is covered with alfa grass, and much of the Tell itself is probably natural grass land. In Eurasia the steppe region forms a continuous belt from Austria-Hungary to western China. The southern border is, in the west, a region of Mediterranean climate, and, in the east, dry desert. On the east there is gradual transition, with increasing rainfall, to the monsoon region of the Pacific coast; on the west, rainfall increases again, with approach to the temperate oceanic type of climate in western Europe. Thus the driest part, with light grasses, is in the southwest of Asia and along the north of the Central Asian desert. The available moisture increases as we go northward, with more rain and lower mean temperature. Hence all the west, north and cast of the belt has enough rain for the heavier grasses.

In North America the chief natural grass region runs north and south rather than east and west. Its driest part, continu-

ous with the savanna land, is on the high plateaux east of the Rockies, and here it runs far north into the basin of the Mackenzie, probably attaining a higher latitude than in any other part of the world. Since the rainfall increases to the east of this line, the growth becomes richer in the heavier grasses, and the belt of temperate forest begins east of Lake Winnipeg and the Great Lakes, and almost along the course of the Mississippi. Smaller areas of grass country occur between the Rockies and the coast ranges north of the arid region; these resemble the Asiatic type of steppe more closely, and are found on the Columbia plateau and Willamette valley, in Oregon, Washington and Idaho.

The steppe region in South America meets the savanna, as already explained, but the position of the Andean axis makes it of comparatively small extent, and in nearly all parts dry. Thin vegetation alternates with the shingle desert. Similarly in Australia the inland parts of New South Wales and Victoria, bordering the Victorian desert, are dry steppes joining the savanna belt farther

north. Considerable parts of West Australia, in the south and near the west coast, are of the same type.

4. *Temperate Forests.*—It has been pointed out that the steppe regions differ somewhat in different parts in that the grass vegetation, which predominates because of the lack of moisture at one season of the year, may be due to summer drought as in the Mediterranean climate, or to winter drought and cold as in the continental climate. The consequences of this difference are still more clearly marked upon the temperate forest belts, because in those parts of the Mediterranean regions which have enough rain for tree growth the winters are not cold, hence the "annual" characteristics are not fully developed, and there is a strong tendency to retain the "evergreen" type of the tropical forests. The "evergreen oak" is, in fact, the typical tree of what may appropriately be called the sub-tropical forest. Again, the oceanic climate on the west has a small range of temperature, and in consequence coniferous trees quickly replace the sub-tropical evergreens in higher

latitudes. Where the forest belt adjoins the true continental steppe, however, the trees are deciduous; the "annual" movement is marked by a quite distinct resting time during the winter, and a fresh covering of leaves appears at the beginning of the active period in spring.

The coniferous trees of the colder forests yield by far the larger part of the world's supply of useful timber. Many of the woods of the deciduous trees are of great economic value, but coal and iron are now used for many of the purposes for which these woods were once required in quantity. The pine woods are softer and more easily worked, and not only is the demand for the old purposes, such as house-building, increasing, but newer uses, as the making of wood pulp for paper manufacture, are constantly being devised. So great is the demand that many parts of this region are now under careful regulation, fresh trees being planted to replace those taken out, but it is doubtful if the supply from at least the more accessible areas would meet the present demand if the rate of

abstraction were nowhere greater than that of replacement by fresh growth. The question is one which, if not yet acute, has already appeared above the economic horizon, and it makes it all the more unfortunate that so few trees in the tropical forests, which cover such vast areas that are apparently of little possible use for anything else, furnish useful timber. The problem may perhaps be solved one day by cultivation; scientific sylviculture may breed a new tree which will grow in the basin of the Amazon or the Congo and yield a wood like common deal. But the labour difficulty will in all probability remain.

The exact position and extent of the natural region of temperate forest is now, in many parts of the world, almost impossible to discover, so much of it has been cleared by the hand of man. Sub-tropical forest occurs in the south-east of Cape Colony and in Natal, and is practically continuous with the tropical forest of the coast region north of the Zambesi. Here the natural conditions are known, but northern Africa and southern Europe, indeed the whole of the Mediterranean climatic

region, has been the "home of civilization" for so long that it is impossible to say precisely how much is steppe and how much natural forest. Generally, however, in the west, through the region of the Atlas into Algeria the rainfall from the cyclones of the Atlantic is sufficient for evergreen forest, while to the east the steppe comes farther north, and the possible forest is restricted to a narrower strip which eventually dies out in south-western Asia. Much, of course, depends upon local configuration, weather slopes with a high rainfall being forested while dry lee slopes are steppe. Similar conditions occur in the other smaller regions where the Mediterranean climate is found, and attention must also be paid to the inner margin of the Asian monsoon region in its northern part, where, for reasons which will be obvious, there is much forest of the sub-tropical type, as in the mountainous parts of south-western and western China.

The temperate forest, properly so called, probably formed a complete ring round the northern continents north of the regions of

sub-tropical forest and steppe. On the western sides of the continents the trees were probably always mostly coniferous, but as the climate becomes more continental eastward, deciduous trees occupy a belt on the side next the steppe, and the coniferous trees keep to the north. It is impossible to fix the northern limit of deciduous trees with confidence, at least in western Europe, but the natural region of temperate forest certainly includes all western Europe, the forest belt which extends across Russia and Siberia (joining up with the monsoon region) and is continued through the basins of the Yukon and Mackenzie to eastern Canada and the part of the United States which lies east of the Mississippi. The southern mountains of Alaska cut off the coastal strip on the Pacific slope, but this temperate forest region extends north-eastward through British Columbia and so joins the main belt.

The only regions in the southern hemisphere which come under temperate forest conditions are the narrow western slopes of southern Chile and southern New Zealand.

The polar limit of the temperate forest is determined by temperature. As there is practically no land, the southern hemisphere does not come into consideration; only a few islands stud the otherwise unbroken belt of the Great Southern Ocean, and in them the weather is too stormy for tree growth. The coast of the Antarctic continent is within the zone of the cold desert far beyond the reach of vegetation. In the northern hemisphere the forest becomes gradually sparser and more stunted, and the characteristic flora of the *tundra* takes its place. In the tundra the ground is frozen, except that in summer thaw penetrates for a foot or two below the surface, flooding the soil with ice-cold water. Only the lowliest forms of plant life survive under such conditions, and of these only the reindeer moss, and in the more favoured spots a few berries, are of even local value. The tundra covers a stretch of varying width from northern Sweden to Bering Strait, and along the northern coast of Alaska through the "barren lands" of North America and the Arctic archipelago. On

account of its great elevation, Greenland is mostly covered with ice and snow all the year round; the cold desert comes down into quite low latitudes.

We have, in the foregoing, tried to give in barest outline the broad features of the vegetative regions, and to bring them into some relation with the climatic regions described in preceding chapters. It will be apparent that much has been omitted for the sake of simplicity; the varying influence of elevation, for example, has been scarcely touched upon; and the desirableness of further subdivision, as in the case of subtropical conditions, has suggested itself as we went along. Subdivision and the recognition of minor features call at once, however, for greater precision in the quantitative estimation of all the elements, vegetative as well as climatic, and this would lead us into matters quite beyond the scope of this book. The difficulties of the subject also increase very rapidly, partly through the meagreness of our knowledge of the distributions in most parts of the world and partly because the more

complex relations which exist between climate and plant life, and the relative importance of other things, like the nature of the soil, are still very imperfectly understood. Meanwhile we repeat that the regional divisions we have described are to be taken quite generally, as major areas having certain hinterland spheres of influence rather than hard and fast frontier lines for their boundarics, and here and there *enclaves* of quite considerable area, wherein conditions are abnormal or anomalous. It may be well to conclude this chapter by referring to what is perhaps the most important type of such abnormal districts.

The course of a great river coming from a region where rain is abundant, may lie through a region where the rainfall is moderate—either because the annual total is small or because of a long dry season—or through one where rainfall is deficient or even absent. If this latter condition occurs in the upper part of the course, where the river is actively eroding its bed, then probably the rivcr bed lies far below the general surface of the land in a narrow gorge or cañon, for there is no local weathering or action of

tributary streams to open out a valley. Such a region is the most hopeless in the world; water is close at hand, but the distance being vertical and not horizontal, irrigation is impossible and the land remains desert. The arid waste around the Grand Cañon of Colorado has abundant water only a mile away—but at the bottom of the cañon. In the lower part of the river course the conditions are reversed. The river perhaps floods once or oftener annually, and its action is now constructive; it brings down quantities of fresh alluvium and spreads water in abundance. The action is probably best seen at the river's mouth where a delta is growing, but it may extend through long distances, as in the Ganges valley where rapid streams from the mountains are collected in swamps and drained away by a great river flowing along the base of the foot-hills, or over wide areas where such streams debouch, and are gathered together on a great plain, as the five rivers of the Punjab in India, or the basin of the Hwang-ho in northern China. Clearly much depends on the relation of the season of flood to that of

rainfall, if rainy season there be. Lower Egypt has no rainfall, and the flooding of the Nile comes when the rain of the monsoon in Abyssinia drains to the lower river; the melting of snows in the mountains of Armenia brings water to Mesopotamia in summer, the dry season; and the tributaries of the Indus and the Ganges, by bringing water from the melting snows of the Himalayas, have an effect equivalent to strengthening the monsoon rains and increasing the length of the wet season.

CHAPTER X

CLIMATE AND MAN

Civilization begins where man is able to provide himself with food and a minimum of clothing, and has time left to think about other things. Progress in civilization of this sort means possession of appliances and skill which make it possible for a community to produce more food than it wants, in a form which will not quickly perish; and in certain cases also to devise methods of transporting the surplus to other communities who produce less food than they require but neverthcless possess a surplus of some other commodity. Until some progress of this kind has been made man remains merely a successful member of the fauna of the district in which he lives. In forest region or grass region he wanders about seeking what he may devour—he is then mostly a carnivorous animal—and the radius of his wanderings is mainly determined by the difficulty of obtaining sufficiency and by the nature of his domestic arrangements.

In the dry steppe man probably learned in very early days to tame certain animals, and so eventually became the owner of flocks and herds, with which he travelled from place to place seeking pasture, greatly aided in the old world of Eurasia by having horses and other quickly moving beasts of burden, which were wanting in the American grass countries. The nomad patriarch found no natural defences in the plains over which he roamed; indeed, he could not have tied himself to any kind of suitable headquarters; and the best pastures were always liable, and even likely, to be coveted by other patriarchs. Hence, some sort of political instinct would soon appear, the art of governing and defending by various arts would be acquired. But there would be no settled life, no escape from the ceaseless care for provision and protection.

In the forest region man merely employed himself like other carnivorous animals in hunting. Eventually he left his family in a den or lair as they did, and fared forth alone as they did, only he probably ranged to greater distances. No doubt he devised

improved weapons from time to time, which made things easier, but even the life of the patriarch was denied him: what progress there was came through the home life of the mother, or matriarch, left behind in some place of perhaps doubtful security.

But in the moister grass regions, usually near the edge of the forest, or in equivalent parts of some monsoon regions, man, or more probably woman, discovered that certain heavy grasses yielded seeds which when dried in the sun formed a food-stuff good to eat and capable of being preserved for an indefinite time by the mere process of drying. What these grasses precisely were, or where they originally grew, no one can say: knowledge of this is lost—for the present at least—although it may be recovered. But we do know that at a quite early stage primitive forest man or his wife took advantage of the opportunities afforded by the settled life possible where food can be stored, and succeeded by some process of selection in greatly improving upon these wild grasses, and increasing their yield many-fold. This cultiva-

tion followed, and still follows, two main lines: the two great cultivated crops of the world are, and always have been, rice and wheat.

Rice cultivation is a difficult art, and the area to prove suitable to the crop has to satisfy exacting conditions. Temperature must average at least about 70° F. during the six months of growth, and during most of that period the water supply must be under complete control. A "paddy" field has an impermeable subsoil or retentive *pan*, or ground water close to the surface, and arrangements must be made for flooding and drying at will. The seed is sown in mud or under water either on the field or in beds from which the seedlings are afterwards planted out. Every night the young plants are flooded to prevent damage by cold, and every day the water is drawn off to avoid burning by the sun. At a later stage the soil is usually kept flooded continuously. As the plants change colour when ripening begins, the ground is gradually allowed to dry and harden, against the harvest.

Now great heat and excessive moisture,

with a drying period to follow, are, as we have learned, characteristic of the monsoon regions, or what, by irrigation or otherwise, may become their equivalent. And it will be understood from what has been said that rice cultivation is not agriculture as we understand it, but rather what we should call gardening—labour not so much arduous as continuous. But rice gives the largest yield per acre of any of the great crops (p. 250); a small area produces sufficient for the cultivator and his family. Hence we find in the greatest of the monsoon regions—where probably the original wild rice first grew, and whence, as it would seem (see volume on *The Dawn of History*), primitive man originally took his descent—a dense settled population [now amounting, according to various uncertain estimates, to from one-fourth to one-third of the human race] engaged in agriculture or horticulture. Such a population is immobile—as all gardeners are; has little skill of politics or government, and is at the mercy of uncouth nomadic politicians of the patriarchal type. But it has leisure—as all gardeners have; and so these regions have pro-

duced the best of the skilled handicrafts, and at least the germs of all the reputable systems of philosophy and religion. Southern and eastern Asia, India and China—diverse in race, caste or its equivalent, and language, through isolation—differ in accessibility from the steppe or the ocean, but they have been and are governed by foreigners. There is no greater testimony to the wealth of rice-producing lands than the number of large towns which subsist on the districts round about them, and not, as is mostly the case in the modern "west," on vast areas with converging lines of rapid communication and transport. Perhaps the most important feature, however, is that the natural rice area is rarely capable of extension by artificial means, except by works on a very large scale. Deficient water supply can no doubt be made good by irrigation, and many parts of the savanna regions are not beyond the resources of modern engineering, as has been shown during recent years in Texas and elsewhere. Tropical forest can also be cleared and the ground made available for rice cultivation, but here again difficulties are formidable even with modern

appliances, so strong and aggressive is the forest growth in reclaiming its own. The temperature limit is inexorable, and so we find that rice still practically remains the product of the monsoon region, consumed by the innumerable small communities (though not necessarily by the individuals) cultivating it. No commodity produced in such large quantity enters so little into international trade.

Many varieties of wheat have been elaborated by cultivation, and with them we may for our present purpose include such allied cereals as oats and barley, and even rye. The climate best suited to wheat on virgin soil is that of the margin of the steppe next the temperate forest. A moderate rainfall is necessary during the earlier stages of growth, and warmth and sun later for ripening. The total amount of rain required is not great—it varies, of course, with the seasonal distribution and the temperature. Wheat ripens with comparatively low maximum temperature, but it survives in regions of great heat provided the heat comes after and not with

the rain, because it ripens quickly. This adaptability gives the crop a wide range, and the wheat area in which it is only necessary to remove the natural grass and sow the seed in order to get an abundant harvest is of enormous extent. It has on one side the fixed boundary of the forest, and on the other the steppe too dry for any but the lighter grasses —often a very uncertain frontier.

The long tract south of the temperate forest in Russia and Siberia (p. 190) is the largest continuous wheat region in the world, but in Eurasia and northern Africa wide stretches of the Mediterranean region next the evergreen forest-lands may be included. In North America the central belt west of the forest runs far north: although certain in rainfall it suffers somewhat from rapid changes of temperature, damage by frost being not infrequent. In the west the wheat area lies south of the forest, on the Columbia plateau and in the valleys. Argentina and south-eastern Australia have the largest areas of this type in the southern hemisphere.

Wheat cultivation under these conditions

requires but little labour, and that for only a short period of the year. Seed-time in early spring is followed by harvest before summer is over. The yield "per acre" is not nearly so great as rice (p. 250), but, on the other hand, the labour of a small number of inhabitants is sufficient for a large area, and that area will produce a great deal more than they need. Also there are easier crops to grow for themselves, as oats, barley and rye. Hence we may have in a wheat region either a dense population, of which only a small proportion is concerned with the production, or a sparse population, in which case the surplus wheat may be exported. But here other elements come in. Wheat is an exhausting crop, and the yield per acre diminishes greatly after the first few years, because in such regions there is not likely to be any natural process of renewal of the soil as happens in the rice regions. There is therefore constant pressure to move on from old settlements to new. Again, the great wheat region is the best part of the steppe, and in such wide plains the cultivator has no natural defence :

in early times he doubtless suffered much from the uncivilized patriarch of the drier steppe, and had in self-defence to retain to some extent the patriarchal methods of the nomadic life. Progress in settlement was slow.

It is therefore easy to see why the great wheat regions of the true steppe have never acquired a dense settled population like the rice areas. The wheat surplus, if it could be produced, had to be disposed of by export, otherwise it was not worth producing, and we probably find in this the beginning of the modern type of trade—the heavy bulky trade in food-stuff—to be distinguished from the transcontinental type of trade in "valuable" articles, like spices, dyes and precious stones.

The essentials of early Western civilization are in effect those of a community based upon some small central region originally able to feed small numbers, and naturally easy to defend—an island, or a district isolated by surrounding mountains, or forests, or deserts, and yet open to a route by which food supplies could be obtained. Food came in the form of wheat, and in the wheat-producing

country protection of some sort was necessary for the cultivator; the central power had to be responsible for military occupation. Now trade means transport, and transport of heavy goods by land was, and still is, much more difficult and expensive than transport by sea. All the greater wheat regions, from the nature of their climate, lie far from the sea, at least in the Old World, with one great exception, the Mediterranean. Hence we find that from whatever part of the world the wheat-growers may have originally set out (see again *The Dawn of History*), their civilization, with its colonial system, developed first in Phœnicia, and Greece, and Rome, where the sea gave access to the fertile regions on the African coast and round the Black Sea. These regions were "occupied" more or less completely by the construction of lines of land transport, *e.g* the "Roman" roads, which made military movements and carriage to the coast comparatively easy. The fundamental structure remains to this day: modified only in respect that better agriculture, with better seeds and more powerful appliances, make

the labour required to produce a given quantity of wheat less than it used to be; and improved means of land transport have made protection against the patriarch (where still necessary) so easy, and carriage even over long distances to the coast so cheap, that the real continental steppe is coming quickly under cultivation.

But since wheat flourishes even in hot regions (if a proper supply of moisture is available), it follows that the wheat-producing area can be extended into the dry parts of the steppe, and even into the dry desert, if means of irrigation can be found. Temperature may be high even in the early stages of growth if there is enough water, provided the water is withdrawn in time for the final stages of growth and ripening. These conditions are often satisfied (p. 229) in the case of great rivers subject to periodic flood: the lower parts of their courses and their deltas having the further advantage that the alluvial soil is renewed automatically, as in the normal rice regions, by flooding, while the district is probably protected either by surrounding

mountains, or by forest, or by desert. There is therefore no longer any obstacle to the growth of a dense settled population, all the members of which cannot, or at least need not, be employed in agriculture. The conditions, *e.g.* those of Lower Egypt and Mesopotamia, approach indeed very closely to those of the rice-growing monsoon areas, but we observe that they necessarily extend over very limited districts. This is also true of another type of the same kind, that where wheat is sown near the end of the rainy season in a region of weak monsoon, the temperature of the cold weather season being suitable for growth and ripening: as, for example, in the Punjab and other parts of India not suited to rice.

It is evident that with the mobility inherent in all the accessible wheat regions, except the small districts naturally irrigated—districts which would not be long in having their resources fully taxed—the question of artificial extension of the wheat area must have arisen in very early times. The naturally-irrigated districts could be considerably extended by engineering works, and we know that this was

done in Egypt and Mesopotamia, but the magnitude of the works soon proved too great even for the extraordinary skill and resource of the engineers of those days, and the method was practically abandoned for thousands of years: it has, in fact, only been reintroduced in modern times since "power" became available—the old schemes on the Nile and the Shat-el-Arab have been revived, extended, and in part executed; and dry steppe and desert brought under cultivation in northern Africa, and on a much larger scale in the western United States. Modern engineering offers almost unlimited prospects in this direction.

But with the end of early irrigation works, expansion began on the other side. Given a reasonably dry and sunny period during the summer, wheat will ripen with quite low temperature. Winter rain need not affect it, for it can be sown in the spring; but if the winter rain is not accompanied by too low temperature it may even prove an advantage, for "winter wheat" can be sown in the autumn, germinate and grow for a time, and

then pause, perhaps warmly covered by a layer of snow, and start again in spring with much progress made before "spring wheat" is even sown. Wheat will therefore grow and ripen over a very large part of the temperate forest zone, and the story of two thousand years of Western civilization is expansion from the Mediterranean by clearing the forests of western and northern Europe, wherever the surface is level enough to allow of cultivation. The process was, in its early stages at least, extremely slow, but the axe and the pick—the implements still mostly in use for the purpose—were early inventions: there was no increasing difficulty or final stop imposed, as with irrigation works.

Forest-clearing also supplies timber, and much of the European forest on sloping ground was no doubt cleared rather to get the timber—difficult stuff to transport—than to make room for wheat. From the wheat-growing point of view the clearing has, in fact, often been carried too far, for in the strictly oceanic type of climate wheat scarcely ripens because of the lack of dry sunny weather in summer.

In western Europe and the British Isles only the lee-sides of the coastal ridges grow wheat successfully, and on the cleared slopes facing the Atlantic we find the anomalous and purely artificial condition of a wet grass region. Here grasses grow or rest all the year round, the lush pastures are always green, and hay has to be "saved" or dried with infinite care and preserved under cover. The conditions are perhaps more fully realized in Ireland than anywhere else; the term "Irish pasture" may be suggested as descriptive.

The dry steppe-regions, where irrigation cannot reach or has not reached them, are still consecrated to the keeping of flocks and herds, or "ranching," as we now term it. In many parts of Central Asia the nomad patriarch still wanders undisturbed, and makes his way into unoccupied parts of potential wheat regions; but in America the "cowboy" on the plateaux east of the Rockies, or the "guacho" of the Argentine, has come from settled countries. He has not acquired entirely nomadic habits, and, thanks to the railway, he does not need to. Cattle and

horses are characteristic of the moister parts of such regions in Canada and the United States, and sheep—for wool or mutton—of the drier parts, as the Australian Riverina and the Canterbury Plains of New Zealand.

The natural and artificial conditions described may be usefully represented by a diagram. In Fig. 10 the part below the horizontal line AB may indicate the climatic conditions in the temperate zone, the strip between AB and CD the natural vegetative regions with the hatched column showing the parts available for wheat. Above CD are shown the effects of man's interference.

Wheat production has become greatly modified in modern times by the elaboration of varieties adapted to different climates—wheats to withstand the frosts of Manitoba, the strong heat of the Punjab, and so on. The available area, cleared or not, is thereby extended. Even more important is the introduction of methods of replacing the soil constituents abstracted, by rotation of crops, addition of manures, and other devices of "intensive" cultivation. These lessen or re-

move the pressure towards migration of wheat areas—which was somewhat relieved even in early times by "resting periods," the "three-field system," and the like—and favour the dense settled population. The present position is that the world's wheat supply comes

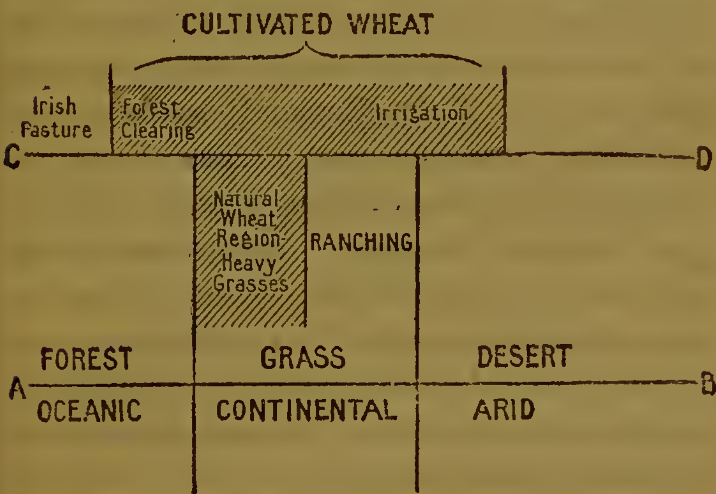


Fig. 10.

from three distinct types of region: (1) the new lands, recently taken up in virgin soil, as in Manitoba, and yielding some twenty bushels (of 60 lb. each) per acre; (2) old rich lands continuously cropped from time immemorial, but from want of skill, or capital, or labour, or enterprise, retaining the "ex-

tensive" method and returning nothing to the soil, as in southern Russia, yielding only some eight bushels to the acre, but exporting most of it, the producers living on cheaper grains such as rye; (3) old lands cultivated according to the "intensive" method of agriculture, or rather gardening (approaching the labour of rice cultivation), and producing from thirty bushels (England) to forty-two bushels per acre (Denmark). The success or importance of these types depends chiefly upon means of transport, for the consuming areas are still concentrated, although they are now centres of manufacture rather than, or as well as, those of military power. The following table sums up these facts and gives corresponding figures with regard to rice, for in rice cultivation Burma may be taken as analogous to Manitoba, Bengal to Russia, and Texas to Denmark.

YIELD PER ACRE IN POUNDS.

	Denmark.	Manitoba	Russia.
Wheat	2500	1200	480
	Texas.	Burma.	Bengal.
Rice	2700	2500	1200

To what extent the full capacities of the different types of region are being drawn upon no one can say. Rice, as always, enters little into trade, but wheat, with new regions and new lines of transport, is still—and seems likely to remain—the chief food-stuff exported from the region of production. In the year ending August 31, 1911, North America—much of which is rapidly acquiring a dense settled population with a large consuming "class" —exported some 65,000,000 bushels of wheat. The Argentine and Australia, with large areas undeveloped, but still larger areas of uncertain yield, exported about 90,000,000 and 78,000,000 bushels respectively. Russia, with large areas of low yield and control of much land still untouched, exported 200,000,000 bushels. The total export for the year is estimated (*The Times*, Sept. 15, 1911) at 500,000,000 bushels, or 30,000,000,000 lb. Large forests remain to be cleared and vast deserts can still be irrigated. The increasing demand for timber will at no very distant date restrict the extension of the wheat supply by the first method, but the application of modern

engineering to irrigation is only beginning. And after that there remains the intensive system hitherto applicd only to the smallcst districts, and probably at the beginning of its career. We have to observe that wide application of its methods means a continuous approximation to thc horticulture of the rice regions. So perhaps the future, at least during a transition period, is to the "Oriental."

After some thousands of ycars we know something about wheat cultivation, and perhaps a little about allied cereals, but about other crops of temperate climates—almost nothing—except that the potato, transplanted from a dry climate in the Andes to moist regions such as Ireland, becomes spccially prone to attack by the "potato disease" (latc blight). One point only is clear, that the ultimate controlling factor, the one which there is least hope of being able to modify in any way—and therefore the one we nced to know most about—is climate.

BIBLIOGRAPHICAL NOTE

For the purposes stated in the earlier chapters, Dr. H. R. Mill's *Realm of Nature* (Murray) is the best text-book of Physical Geography in English, although it is not everywhere easy reading.

Detailed information as to methods of observation is best obtained from the "Instructions" issued by the Government departments of various countries, as the British Meteorological Office and the United States Weather Bureau, and by representative societies, as the *Hints to Observers*, published by the Royal Meteorological Society, and the meteorological section of *Hints to Travellers*, Royal Geographical Society.

In Meteorology, as in all branches of geographical study, incessant use of appropriate maps is absolutely essential. The official departments at home and abroad publish various atlases, and the great series of maps accompanying the volume on "Atmospheric Circulation" in the *Report of the Expedition of H.M.S. Challenger* is to be found in some libraries. More comprehensive, and at the same time more accessible, is Bartholomew's *Atlas of Meteorology* (Constable, 1899), edited by Dr. A. Buchan with the collaboration of A. J. Herbertson and J. G. Bartholomew. See also Sir John Eliot, *Climatological Atlas of India*, 1906. Most modern hand-atlases include more or less adequate climatological maps. A map showing the seasonal distribution of rainfall is important.

Amongst text-books, the final and authoritative works are two by Dr. J. Hann, *Lehrbuch der Meteorologie* (Tauchnitz, 1906) and *Handbuch der Klimatologie* (Engelhorn, 1908–11). The general part of an earlier edition of the latter work has been translated by R. de C. Ward in a *Handbook of Climatology* (Macmillan, 1903). The best general text-book in English is still W. M. Davis's *Elementary Meteorology* (Ginn, 1894). Reference may also be made to R. de C. Ward, *Climate* (Murray, 1908), and Willis L. Moore, *Descriptive Meteorology* (Appleton, 1911). In German, Hann's *Die Erde als Ganzes, ihre Atmosphäre und Hydrosphäre* (Freytag, 1896) forms the first part of *Allgemeine Erdkunde*, a volume of Kirchhoff's *Unser Wissen von der Erde*, and is less formidable than his larger works. The

meteorological chapters in Supan's *Grundzüge der physischen Erdkunde* (Veit, 1907) are specially valuable in their relation to the other parts of an excellent book. See also the articles "Meteorology" and "Climate" in the latest edition of the *Encyclopædia Britannica.* Important books on special aspects of meteorology are Sprung, *Lehrbuch der Meteorologie* (Hoffmann und Campe, 1885), Ferrel, *Popular Treatise on the Winds* (Macmillan, 1890), and Hildebrandsson and Teisserenc de Bort, *Les Bases de la Météorolgie dynamique* (Gauthier-Villars, 1898–1905); also a series of translations of papers, edited by Cleveland Abbe and published (various years) in the *Smithsonian Miscellaneous Collections.* Reference has been made in the text to W. J. Lockyer's valuable papers published for the Solar Physics Committee (1909 and 1910).

The relation of Meteorology and Oceanography, so far as it is discussed in this book, is dealt with by Dr. Otto Pettersson in various papers (see especially *Scottish Geographical Magazine,* 1894, and *Geographical Journal,* 1904), and also by the writer in "Circulation of the Surface Waters of the North Atlantic Ocean" (*Phil. Trans.*, 1901); also papers by W. Meinardus and G. Schott in the *Meteorologische Zeitschrift* and *Annalen der Hydrographie* (various years).

Recent progress is largely concerned with the exploration of the upper atmosphere. In this country this is associated with the names of W. H. Dines, W. N. Shaw, R. G. K. Lempfert, E. Gold and others, whose papers are to be found in the publications of the Royal Society, the Meteorological Office, the Royal Meteorological Society (Quarterly Journal) and the Reports of the British Association. See also Arthur Wagner, *Beiträge zur Physik der freien Atmosphäre,* Bd. iii (Leipzig, 1909).

Serial publications containing papers and reports on meteorological research are: *Meteorologische Zeitschrift* (Brunswick), *Ciel et Terre* (Brussels), *Annalen der Hydrographie* (Hamburg), *Monthly Weather Review* and *Bulletin of the Mount Weather Observatory* (Washington), *Quarterly Journal of the Royal Meteorological Society,* and *Symons' Meteorological Magazine* (London), also *Journal of the Scottish Meteorological Society* (Edinburgh).

For plant geography (Chapter IX) the reader is referred to *Plant Geography,* by A. F. W. Schimper, translated by W. R. Fisher (Clarendon Press, 1903). Information as to the relation between Man and the climate in which he lives will be found in the volume in this series on *The Dawn of History.* See also the Note on Books at the end of that volume.

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By F. L. Paxson, Professor of American History, Wisconsin University. (With Maps.) "A stirring study."—*The Guardian.*

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